



# **SOLID STATE ABSTRACTS**

*an abstract journal devoted to the  
theory, production and use of solid state materials and devices*

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PHYSICS  
METALLURGY  
ELECTRONICS

METALS  
SEMICONDUCTORS  
SUPERCONDUCTORS  
PHOSPHORS  
MAGNETICS  
DIELECTRICS



# SOLID STATE ABSTRACTS

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Abstracts 10,000-10,315

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# ABSTRACTS OF THE SOLID STATE LITERATURE

## METALLURGY AND CHEMISTRY OF SOLIDS

### THERMODYNAMIC PROPERTIES OF ALLOYS

10,000 SOLUBILITY OF OXYGEN IN GERMANIUM by W. Kaiser and C. D. Thurmond (Bell Labs.); J. Appl. Phys., Vol. 32, pp. 115-118, Jan. 1961

The infrared absorption band at  $11.7\mu$  corresponding to a germanium-oxygen molecular vibration is quantitatively correlated to the chemically determined oxygen content of germanium crystals. The solid solubility of oxygen has been determined as a function of temperature and the precipitation of the second phase  $\text{GeO}_2$  has been observed. Crystals containing about  $10^{17}$  atoms per  $\text{cm}^3$  of dissolved oxygen have been prepared. The maximum solubility appears to be  $2 \times 10^{18}$  atoms/ $\text{cm}^3$ . The heat of solution is 1.2 ev. Silicon in a melt of germanium acts as a getter for oxygen, resulting in the formation of  $\text{SiO}_2$ ; this observation is in agreement with thermodynamical considerations.

Solubility of Ga and Sb in Ge - See 10,031

Solid Solutions of Sm with S - See 10,037

Solid Solution in the Cu-Se-Si System - See 10,005

Micro-Segregation Due to Freezing - See 10,144

10,001 ANALYTICAL SOLUTIONS FOR SOME ZONE MELTING PROBLEMS by H. Reiss and E. Helfand (Bell Labs.); J. Appl. Phys., Vol. 32, pp. 228-232, Feb. 1961

Analytical solutions to the zone melting problem are obtained for any initial distribution of solute for the case of two specific geometries. One is the infinite straight bar and the other is the re-entrant annular ring. The former is particularly interesting because under certain conditions the semi-infinite bar may be treated as infinite. The annular ring calculation provides, among other applications, a means of giving quantitative answers to questions arising in the zone leveling process.

Zone Melting of AgCl and AgBr - See 10,015

10,002 DIFFERENTIAL THERMAL ANALYSIS OF GALENA AND CLAUSTHALITE by J. A. Dunne and P. F. Kerr (Colum-

bia U.); Am. Mineral., Vol. 46, pp. 1-11, Jan.-Feb. 1961

Differential thermal analyses of both natural and artificial lead-sulfur-selenium compounds are reported. Thermal curves of twelve natural galenas exhibit a striking consistency regardless of the genetic associations of the minerals studied. In certain instances, limited ( $5-10^\circ\text{C}$ ) variations from the over-all average peak temperature of  $783 \pm 2^\circ\text{C}$  appear, which seem to be related to lattice parameter differences. A range of synthetic compounds at ten molecular per cent solid solution intervals from PbS to PbSe has been formed by pyrosynthesis. X-ray measurements of the series showing unidimensional lattice variation in relation to composition plot as a straight line. Thermal data, on the other hand, produce a more complex plot which may be interpreted in terms of both lattice energies and the nature of the observed reactions. DTA reaction temperatures are systematically related to cell dimensions in the range PbSe -  $\text{PbS}_{0.7}\text{Se}_{0.3}$ . DTA data taken from samples in the compositional range  $\text{PbS}_{0.7}\text{Se}_{0.3}$  - PbS are believed to be affected by incongruent anion behavior and surface oxidation effects. Data on pyrosynthesis reaction (formation) temperatures exhibit a fundamental and systematic relation to molar composition throughout the entire compositional range.

Use of Martensitic Transformations in Binary Resistance Devices - See 10,188

Martensitic Transformation in Na - See 10,140

Phase Transformations of  $\text{AgFeTe}_2$  - See 10,092

10,003 VAPOR PRESSURE OF SILICON AND THE DISSOCIATION PRESSURE OF SILICON CARBIDE by S. G. Davis (Rutgers U.); D. F. Anthrop (GE), and A. W. Searcy (U. California); J. Chem. Phys., Vol. 34, pp. 659-664, Feb. 1961

Values of the vapor pressure of silicon and the dissociation pressure of silicon carbide obtained from total weight loss experiments with Knudsen effusion cells are reported. Combination of the measured data with known entropies yields at  $298^\circ\text{K}$  for the heat of sublimation of silicon to silicon atoms  $108.4 \pm 3$  kcal and for the heat of the reaction  $\text{SiC(s)} = \text{Si(g)} + \text{C(s)}$   $126.0 \pm 3$  kcal. From the pressure studies and from phase equilibria for the condensed phase silicon-carbon system, the heats of formation for both the cubic and hexagonal modifications of silicon carbide are concluded to be  $-15.0 \pm 2$  kcal.

10,004 STABILITIES OF GASEOUS MOLECULES IN THE Pb-Se AND Pb-Te SYSTEMS by R. F. Porter (Cornell U.); J. Chem. Phys., Vol. 34, pp. 583-587, Feb. 1961

Mass spectrometric analyses of the vaporization products of



## THERMODYNAMIC PROPERTIES OF ALLOYS (Cont'd)

phases near compositions PbSe and PbTe indicate that these substances vaporize primarily as molecular PbSe(g) and PbTe(g), respectively. Ion fragmentation processes originating from electron bombardment of vapors effusing from a conventional Knudsen cell interfere with quantitative determination of thermochemical dissociation energies of PbSe(g) and PbTe(g). The use of double oven-type Knudsen cells provided a means for the study of the dissociation of PbSe(g) and PbTe(g) into the gaseous elements. Dissociation energies of PbSe(g) and PbTe(g) were found to be  $61.5 \pm 2.5$  and  $51.4 \pm 2.0$  kcal/mole, respectively. The dissociation energy of Te<sub>2</sub>(g) was found to lie close to the published spectroscopic value.

10,005 LATTICE SPACINGS IN THE SYSTEM COPPER+ GERMANIUM+ SILICON by J. H. Foley and G. V. Raynor (U. Birmingham); Trans. Faraday Soc., Vol. 57, Part 1, pp. 51-60, Jan. 1961

Lattice spacing measurements for the close-packed hexagonal  $\zeta$ -phase in the system copper+silicon, and for the continuous solid solution formed between this phase and the corresponding  $\zeta$ -phase in the copper+germanium system are reported. In the binary alloys, the a-spacing increases with increase in electron/atom ratio, while the c-spacing and the axial ratio decrease; an increase in slope of the curve of a-spacing against electron concentration at approximately 1.4 electrons per atom is consistent with the onset of overlap of electrons in directions at right-angles to the hexagonal axis from the appropriate Brillouin zone at this point. The increase in a is accompanied by a decrease in c such that  $a^2c$  remains a linear function of composition throughout the range of homogeneity of the hexagonal phase. In the ternary system, the most striking feature is the constancy of the axial ratio at compositions corresponding to a constant electron/atom ratio. The results obtained are briefly discussed, together with the relationship between the lattice spacings of the face-centered cubic primary solid solution and the a-spacings of the close-packed hexagonal phase with which it enters into equilibrium.

## CRYSTAL STRUCTURE (including Imperfections and Impurities)

10,006 THE IONIC DISTRIBUTION IN THE GARNETS Gd<sub>3</sub>Al<sub>3</sub>Fe<sub>2</sub>O<sub>12</sub> AND Y<sub>3</sub>Al<sub>3</sub>Fe<sub>2</sub>O<sub>12</sub> by C. E. Miller (Bell Labs.); J. Phys. Chem. Solids, Vol. 17, pp. 229-231, Jan. 1961

An analysis of quantitative x-ray powder diffraction intensity data made with the purpose of determining the ionic distribution in Gd<sub>3</sub>Al<sub>3</sub>Fe<sub>2</sub>O<sub>12</sub> and Y<sub>3</sub>Al<sub>3</sub>Fe<sub>2</sub>O<sub>12</sub> is reported. It has been found that the exact distribution cannot be determined in this manner. However, the distribution recently deduced by Geller is compatible with the results of x-ray analysis.

10,007 THERMAL EXPANSION OF DIAMONDS BETWEEN 25° AND 75°K by S. I. Novikova (All-Union Sci. Res. Inst. Physicotech. and Radiotech. Measurements); Soviet Phys.-Solid State, Vol. 2, pp. 1464-1465, Jan. 1961

Measurements of the thermal expansion,  $\alpha$ , of two natural diamond crystals are reported. One was measured between 20° and

350°K, the other between 20° and 750°K; the values of  $\alpha$  for the two diamonds coincide completely. The results of 14 series of measurements are plotted; the curve shows that  $\alpha$  decreases uniformly with temperature, and approaches zero at approximately 90°K. There is no break in the curve at 470°K, as indicated by a prior work reported in the literature.

Lattice Parameters of KMnF<sub>3</sub> - See 10,099

10,008 CRYSTAL DISTORTION IN COPPER FERRITE-CHROMITE SERIES by H. Ohnishi and T. Teranishi (Hokkaido U.); J. Phys. Soc. Japan, Vol. 16, pp. 35-43, Jan. 1961

Measurements of cation distributions in the copper ferrite-chromite series and in copper ferrite quenched from high temperatures by the x-ray diffraction method are reported. The lattice parameters have also been measured as a function of chromium ion content and of temperature. The critical fractions of copper ions on 16d and 8a sites for the occurrence of bulk crystal distortion from cubic to tetragonal symmetry are determined. The critical temperature for the distortion of copper ferrite is 360°C. This crystal distortion depends only upon the copper ion distribution. The abrupt appearance of distortion and coexistence of two phases, cubic and tetragonal, near the critical fraction and the critical temperature suggest that this distortion is of the first order as predicted by the statistical theory. From the aging of the distortion, the activation energy for a copper ion to migrate from a 16d site to an 8a site is obtained. From a comparison of the critical fractions of copper ions in this series with those in other mixed spinels, the origin of this crystal distortion is discussed.

10,009 FORMATION OF F CENTERS IN KCl BY X-RAYS by P. V. Mitchell, D. A. Wiegand, and R. Smoluchowski (Carnegie Inst. Tech.); Phys. Rev., Vol. 121, pp. 484-498, Jan. 15, 1961

Measurements of the growth of the F band in undeformed, deformed, and heat-treated KCl crystals at room temperature using 140-kvp x-ray irradiation are reported. The growth curves have been analyzed in terms of the initial concentration of negative-ion vacancies in the lattice before irradiation, rate of formation of new vacancies, rate of electron capture by the initial and by the new vacancies, and bleaching constants. These parameters have been studied as a function of the intensity of irradiation. It appears that the new vacancies are generated at a rate proportional to the square of the intensity of irradiation and inversely proportional to the dislocation density. Deformation increases the concentration of initial vacancies near dislocations, while heat treatment increases the concentration of initial vacancies dispersed in the volume of the crystal. Since neither the jog mechanism nor the Varley mechanism can account for the observations, a new model which accounts for all the observed phenomena is proposed.

10,010 BLEACHING AND RECOVERY OF F CENTERS IN KCl by L. E. Silverman and L. I. Grossweiner (Illinois Inst. Tech.); Phys. Rev., Vol. 121, pp. 1072-1075, Feb. 15, 1961

It is reported that F centers in KCl are optically bleached at room temperature with a minimum light energy of  $20.1 \pm 1.0$  eV per F center. The F band is recovered on further room temperature x-raying with a minimum energy of  $69 \pm 5$  eV per F center. The increase in the M and R bands during optical bleaching of the F band is nullified upon the recovery of the F band by further x-raying. The recovery kinetics are of second order in the number of optically bleached F centers with a rate-constant of  $(7.9 \pm 0.8) \times 10^{-20}$  cm<sup>3</sup>/F center-sec. The rate law requires



## CRYSTAL STRUCTURE (Cont'd)

energy transfer from the bulk lattice and is consistent with an exciton mechanism.

Color Centers in LiH - See 10,119

Radiation-Induced Vacancies in Si - See 10,111 and 10,120

10,011 OBSERVATION OF DISLOCATION IN TELLURIUM by A. I. Blum (Semicon. Inst.); Soviet Phys.-Solid State, Vol. 2, pp. 1509-1511, Jan. 1961

Results obtained using various etchants to display etch pits corresponding to dislocations in plastically deformed Te are discussed. Two etchants produced etch pits in directions parallel and perpendicular to the c-axis. The first etchant, composed of 99 gm  $H_3PO_4$  ( $\rho = 1.55$  gm/cc), one cc conc.  $H_2SO_4$ , and 5 gm  $CrO_3$  (crystalline) was heated to  $90-100^\circ C$ ; the other etchant, composed of 84.8 gm  $H_3PO_4$ , two cc  $H_2SO_4$ , and 4.4 gm  $CrO_3$  was heated to  $150-160^\circ C$ . Photomicrographs of etch pits both normal and perpendicular to the c-axis are shown.

Dislocation Etch Pits in Cu - See 10,044

Copper Decoration of Dislocations in Silicon - See 10,023

Dislocation Contributions to the Elastic Moduli and Damping in Cu - See 10,148

Effect of Dislocations on Carrier Lifetime - See 10,065

10,012 DONOR EQUILIBRIA IN THE GERMANIUM-OXYGEN SYSTEM by C. S. Fuller, W. Kaiser and C. D. Thurmond (Bell Labs.); J. Phys. Chem. Solids, Vol. 17, pp. 301-307, Jan. 1961

Donor equilibria involving the reaction of oxygen with germanium are discussed. The intrinsic electron concentration is shown to be an important factor in determining the equilibrium. The results confirm that four oxygen atoms are involved in the formation of one donor. The standard enthalpy change (71 kcal, 2.97 eV) for the donor formation is somewhat greater than that expected for a  $GeO_4$  structure. The entropy (48 e.u.), however, appears to be much too large for a simple rearrangement model.

10,013 THE EFFICIENCY OF LEAD AS AN ACCEPTOR IN BISMUTH TELLURIDE by A. C. Shekler (Carrier); Symp. Thermoelectric Energy Conversion, Jan. 1961

It was pointed out that, for proper crystal-growth conditions, the acceptor efficiency of lead in  $Bi_2Te_3$  approaches unity as a limit; i.e., all of the lead occupies substitutional sites in the bismuth telluride lattice, and consequently donates a hole to the lattice.

10,014 ANALYSIS OF TRACE IMPURITIES IN SILICON CARBIDE by R. L. Rupp and G. H. Morrison (Genl. Tel. Electronics); U.S. Gov. Res. Rep., Vol. 35, p. 211 (A), Feb. 10, 1961 PB 152 434

An emission spectrographic technique of analyzing trace impurities wherein the sensitivity has been increased by two to three orders of magnitude is described. Refinements in each of the three major components of emission spectroscopy, namely the

light source, the optical system, and the detector have yielded increased sensitivity, with the most marked results being achieved through a better understanding of the volatilization-excitation processes taking place in the light source. Studies using silicon carbide as a matrix have shown that increased sensitivity is most pronounced in the case of the more volatile elements, i.e., As, Hg, P, Pb, Sb, Sn, Tl, and Zn, with Hg and P having been detected down to 5 parts per billion as compared to sensitivities of the order of 10 to 50 parts per million previously obtainable.

Oxygen in Germanium - See 10,000

10,015 ZONE REFINING OF THE SILVER HALIDES by F. Moser (Eastman Kodak Res. Labs.), D. C. Burnham and H. H. Tippins (U. Illinois); J. Appl. Phys., Vol. 32, pp. 48-54, Jan. 1961

Application of the technique of zone melting to AgCl and AgBr in an attempt to obtain large crystals of extremely high purity is described. By measuring distributions in ingots with deliberate impurity additions, both optimum conditions for zoning and distribution coefficients for several impurities have been determined. For AgCl, zone melting in a chlorine atmosphere led to near-ultimate distributions for Cu, Pb, Ni and Fe after passage of 70 zones at a rate of 3 in./hr. The distribution coefficients determined were as follows: Cu, 0.4; Pb, 0.4; Ni, 1.4 and Fe, 0.7. Zone melting in vacuum resulted in similar distributions for Cu, Pb, and Ni, but Fe separated with an effective distribution coefficient slightly greater than one. Under these conditions Mn and Cd separated in a direction opposite to that of zone travel, and Sn, Al, and Sr separated in the direction of zone travel. Zone refining of nominally pure AgCl resulted in crystals which probably contain less than one part in  $10^9$  of Cu and Ni, less than one part in  $10^8$  of Pb, and less than five parts in  $10^8$  of Fe. Limited data on AgBr indicate that in this case, too, useful purification can be obtained. The dark electrical conductivity of the zoned crystals was found to be intrinsic above  $315^\circ K$  for AgCl and  $300^\circ K$  for AgBr.

10,016 A SURVEY OF THE LITERATURE ON THE USE OF ORGANOMETALLIC COMPOUNDS IN THE PREPARATION OF ULTRAPURE METALS by W. A. G. Graham (A. D. Little); U.S. Gov. Res. Rep., Vol. 35, p. 23 (A), Jan. 13, 1961 PB 171 097

A survey of the literature on methods for recovering metals from organometallic compounds is presented. Possible recovery methods include thermal decomposition, photolysis, electrolysis, and hydrogenolysis. These have been appraised from the standpoint of contamination of the product by organic residues. Reaction of metals with gaseous organic free radicals has also been reviewed, but does not appear attractive as a means of purification. Reactions of organic free radicals in solution with metals are also discussed.

10,017 A RAPID AND ACCURATE METHOD FOR MEASURING THE THICKNESS OF DIFFUSED LAYERS IN SILICON AND GERMANIUM by B. Jansen (Philips Res. Labs.); Solid-State Electronics, Vol. 2, pp. 14-17, Jan. 1961

A method of measuring surface-layer thicknesses by making use of the brittleness of silicon and germanium, thus eliminating cumbersome, precise grinding and polishing procedures, is described. The germanium or silicon slice is broken in a special manner to produce a rather flat cleavage surface, in which any disturbing fracture line is more or less perpendicular to the very



## CRYSTAL STRUCTURE (Cont'd)

sharp, long edges. In this surface the exposed p-n junctions are marked as very thin lines by one of the well-known methods (electrolytical, chemical). The distances between these lines or to the edge of the cleavage surface are measured under a high-power metallographic microscope with an eyepiece micrometer. Very thin layers of about  $1\mu$  can be measured. The method can be used for diffused layers, alloyed contacts, or combinations as in the case of alloy diffusion.

10,018 DIFFUSION IN A FERROMAGNETIC ALLOY by J. Stanley and C. Wert (U. Illinois); J. Appl. Phys., Vol. 32, pp. 267-273, Feb. 1961

Measurements of diffusion constants in an alloy of Fe + 18% V over a wide temperature range by a combination of radioactive tracer and anelastic methods are reported. The region of measurement extends over a considerable interval on both sides of the magnetic Curie temperature. The data show a pronounced effect of ferromagnetic spin ordering on diffusion. Diffusion in the well-ordered ferromagnetic state is about 100 times slower than would be expected from extrapolation of data in the paramagnetic region. Part of this retardation appears to be an increase in the activation energy and part a decrease in  $D_0$ .

10,019 DIFFUSION OF BORON IN CARBON by P. S. Kislyi and G. V. Samsonov (Inst. Metalloceramics and Special Alloys); Soviet Phys.-Solid State, Vol. 2, pp. 1563-1565, Feb. 1961

The mechanism of the diffusion of boron in carbon is discussed. Similarity of results obtained with relatively impure (70%) boron and very pure (99.9%) boron indicates the complete removal of admixtures of impure boron during impregnation. For impregnation at  $1940^\circ\text{C}$  for 30 minutes, the diffusion coefficient for boron in carbon was  $6.2 \times 10^{-6} \text{ cm}^2/\text{sec}$ ; under the same conditions the diffusion coefficient for carbon in boron was  $1.8 \times 10^{-6} \text{ cm}^2/\text{sec}$ , indicating a higher mobility of the boron atoms. From the data, the temperature dependence of the diffusion coefficient of boron in graphite is  $D = 3.02 \exp(-28625/T)$ .

10,020 A STUDY OF SUBSTITUTED MnTe by A. J. Panson (Westinghouse Res. Lab.); Symp. Thermoelectric Energy Conversion, Jan. 1961

The doping of MnTe with Li or Na by powder metallurgy techniques was discussed. The reaction  $\frac{x}{2} \text{Li}_2\text{Te} + (1-x) \text{MnTe} + \frac{x}{2} \text{Te} = \text{Li}_x\text{Mn}_{1-x}\text{Te}$  was utilized. The  $\text{Li}_2\text{Te}$  or  $\text{Na}_2\text{Te}$  was prepared by reacting Te with the alkali metal dissolved in liquid ammonia. The solubility limits of the dopants were determined by plotting the Seebeck coefficients as a function of log of the dopant concentration. The solubility limit of Li was found to be  $x = 0.06$ . The electrical properties of these materials have been studied as a function of temperature up to  $1025^\circ\text{C}$ . A series of compounds ( $\text{Na}_x\text{Mn}_{1-x}\text{Te}_{1-y}\text{Se}_y$  and  $\text{Li}_x\text{Mn}_{1-x}\text{Te}_{1-y}\text{Se}_y$ ) were also made with Se substituted for Te and their electrical properties have been determined.

10,021 PREPARATION OF UNIFORM RESISTIVITY N-TYPE SILICON BY NUCLEAR TRANSMUTATION by M. Tanenbaum and A. D. Mills (Bell Labs.); J. Electrochem. Soc., Vol. 108, p. 171, Feb. 1961

By the capture of a thermal neutron, the natural isotope  $\text{Si}^{30}$  can be transmuted into the unstable isotope  $\text{Si}^{31}$  which decays by beta emission with a 2.62 hr half-life to the stable isotope  $\text{P}^{31}$ . By means of this reaction, donors can be produced in a

silicon crystal. Because of the uniformity of flux which can be obtained in large nuclear reactors, this technique lends itself to the preparation of uniformly doped n-type silicon. After irradiation the silicon crystal is heavily damaged by the emitted betas, by the recoil of the decaying  $\text{Si}^{31}$ , and by the high energy neutrons that are unavoidably present in the reactor. However, this damage can be removed by annealing at temperatures near  $600^\circ\text{C}$ . The technique has been used to produce n-type silicon with nominal resistivities between 0.1 and 20 ohm-cm. The resistivity of the resulting crystals was uniform over dimensions of 5 cm to within  $\pm 5\%$ .

10,022 ON THE KINETICS AND MECHANISM OF PRECIPITATION OF LITHIUM FROM GERMANIUM by J. R. Carter, Jr. and R. A. Swalin (U. Minnesota); U.S. Gov. Res. Rep., Vol. 35, p. 110(A), Jan. 13, 1961 PB 171 097

An investigation of the precipitation of Li from Ge undertaken to determine (1) precipitation rates in crystals supplied from various sources, (2) the effect of thermal history prior to introduction of Li, and (3) the influence of selective impurity additions (O and Cu) on the kinetics of the precipitation of Li, is reported. The basic technique involved the saturation of a sample of Ge with Li at a high temperature where precipitation of the Li occurred. The progress of precipitation was followed by using electrical resistivity techniques. The precipitation kinetic data followed Ham's theory qualitatively (J. Phys. Chem. Solids 6:335, 1958) if the Li were introduced at a high temperature. The crystals which were obtained from different sources yielded drastically differing values of the apparent nuclei number density. A 2-hr  $900^\circ\text{C}$  anneal of the Ge prior to saturation with Li increased the number of nuclei for all samples. Doping the Li with O and Cu tended to increase and decrease, respectively, the nuclei number density.

10,023 STUDY OF COPPER PRECIPITATION BEHAVIOR IN SILICON SINGLE CRYSTALS by G. H. Schwuttke (Genl. Tel. Electronics); J. Electrochem. Soc., Vol. 108, p. 163, Feb. 1961

An investigation of the precipitation behavior of copper in silicon single crystals containing different amounts of oxygen in the temperature range of  $900^\circ - 1300^\circ\text{C}$  is reported. Precipitation which occurs during the cooling period on structural defects and at random sites throughout the bulk crystal has been detected by infrared transmission microscopy. The shape and crystallographic relationship of the precipitate as related to the silicon matrix has been determined. The reliability of the method of copper decoration for the determination of low dislocation densities in the presence of oxygen has been investigated by comparing copper decoration pictures with x-ray diffraction photomicrographs.

10,024 X-RAY STUDIES ON PRECIPITATION OF METASTABLE CENTERS IN MIXED CRYSTALS  $\text{NaCl}-\text{CdCl}_2$  by K. Suzuki (Nippon Tel. and Tel.); J. Phys. Soc. Japan, Vol. 16, pp. 67-78, Jan. 1961

An examination of mixed crystals of  $\text{NaCl}-\text{CdCl}_2$  containing a few mole per cent of  $\text{CdCl}_2$  by the x-ray method is reported. Use of a particular heat treatment results in the formation of precipitates having a f.c.c. lattice with a lattice constant twice that of the matrix. Another heat treatment results in diffuse spots corresponding to the intensity distribution of rods extended in the  $\langle 100 \rangle$  directions at odd-order reciprocal-lattice points. The crystal structure of the precipitates, which has been identified as  $\text{CdCl}_2 \cdot 6\text{NaCl}$ , is determined, and the main features of the diffuse reflections are explained on the basis of the structure.



## CRYSTAL STRUCTURE (Cont'd)

10,025 PROBLEM OF THE INTERACTION BETWEEN COPPER AND ANTIMONY IN GERMANIUM by A. Ya. Potemkin and V. I. Potapov (Baikov Metall. Inst.); Soviet Phys.-Solid State, Vol. 2, pp. 1668-1700, Feb. 1961

The behavior of Cu in single crystals of pure Ge and in single crystals of Ge doped with Sb is discussed. Upon application of an external field, in the former, Cu atoms acquire a negative charge at temperatures between 540 and 650°C; in the latter, Cu atoms acquire a negative charge at temperatures between 600 and 625°C. In both cases the Cu is displaced toward the positive electrode. Both impurities were present in concentrations less than their solubility limit in solid germanium. Thus, a chemical interaction between Cu and Sb can occur under those conditions of concentration, a conclusion based on the kinetics of the observed mobility of Cu.

10,026 SURFACE MOBILITY OF COPPER IONS ON CUPROUS OXIDE by R. Frerichs and I. Liberman (Northwestern U.); Phys. Rev., Vol. 121, pp. 991-996, Feb. 15, 1961

The motion of  $\text{Cu}^+$  ion vacancies on the surface of cuprous oxide at room temperature under the application of an electric field is discussed. The mobility of the  $\text{Cu}^+$  vacancies has been measured by means of a "time of flight" procedure. The formation of luminescent centers is the unique property of  $\text{Cu}^+$  vacancies that makes them directly observable. The mobility of the  $\text{Cu}^+$  vacancies at room temperature is about  $10^{-11} \text{ cm}^2/\text{volt-sec}$ . The variation of the mobility with temperatures between 28°C to 55°C has been observed. From these data the constants of the diffusion equation  $D = D_0 \exp (\Delta H/RT)$  are computed.  $D_0 = 5 \times 10^{-7} \text{ cm}^2/\text{sec}$ ,  $\Delta H = 8100$  calories. The low values obtained for these constants show that the ionic current follows low-resistance paths formed by the crystal grain boundaries or along the surface of the crystal.

10,027 CREEP OF SILVER ON THE SURFACE OF CERAMIC DIELECTRICS by I. E. Balygin; Soviet Phys.-Solid State, Vol. 2, pp. 1558-1562, Feb. 1961

Creep of silver on the surface of ceramic porcelain dielectrics at an applied dc voltage of two to three kv, in tests ranging from 90 to 114 hours, is discussed. In some cases, migration occurred into the ceramic body rather than on its surface. Theoretical interpretation of the migration, which originates at the anode in all cases, is presented. Photomicrographs taken during the tests reveal creep as a function of time. In similar tests with platinum, no creep was observed.

10,028 SURFACE STRUCTURES AND PROPERTIES OF DIAMOND-STRUCTURE SEMICONDUCTORS by D. Haneman (Brown U.); Phys. Rev., Vol. 121, pp. 1093-1100, Feb. 15, 1961

Low-energy electron-diffraction and secondary electron-emission measurements on (111) and  $(11\bar{1})$  surfaces of GaSb and (100) surfaces of InSb are reported. To account for the diffraction patterns observed both for these materials and previously for Ge and Si, a general model for (111) surfaces of diamond-structure semiconductors is proposed. Every second atom, counting along alternate close-spaced rows is raised with respect to its neighbors, being bonded to the sublayer by three p bonds while the "dangling bond" is s type. The remaining three-fourths of the surface atoms have dangling p bonds and are bonded to the sublayer by trigonal  $\text{sp}^2$ -type bonds. The Ga or  $(11\bar{1})$  face of GaSb has maximum sticking coefficients of  $10^{-5}$  and  $10^{-4}$  for oxygen and  $\text{CO}_2$ , respectively, these values

being 10 times greater than those found for the Sb or (111) face. Multilayer adsorption of oxygen takes place on all the surfaces measured. The oxygen can be removed by heat treatment alone. Evidence is presented to show that diffusion of oxygen into the bulk is an important mechanism for regenerating the clean surfaces by heat treatment. Carbon dioxide adsorbs on GaSb so as to show structure. It apparently deposits as an unbroken molecule, and, unlike oxygen, does not build up several layers.

Structure of ZnS Crystals - See 10,033

Structure of Some II-IV Compounds - See 10,036

## CRYSTAL GROWTH

10,029 GROWTH OF WHISKERS BY CHEMICAL REACTIONS by C. R. Morelock and G. W. Sears (GE Res. Lab.); J. Chem. Phys., Vol. 34, pp. 1008-1009, Mar. 1961

The general conditions for the growth of whiskers by vapor deposition are considered. It is shown that if several reactions are available to grow a given crystal phase, the reaction with the lowest entropy of reaction will allow the growth of near-perfect crystals, at the largest temperature difference between source crystals and growing crystals.

10,030 GROWTH OF SINGLE CRYSTAL BISMUTH TELLURIDE by F. J. Strieter (Texas Instr.); 1961 Symp. Thermoelectric Energy Conversion

The growth of single crystals of bismuth telluride by the Teal-Little method was discussed. Crystals were pulled in a direction perpendicular to the cleavage planes; that is, perpendicular to the c-axis of the hexagonal unit cell. Crystals grown from an initially stoichiometric melt were all p-type. Crystals of n-type material were successfully grown by using iodine doping. Some of the problems encountered in growing the crystals, including various types of polycrystalline growth, scum formation on the surface of the melt, and increased difficulty of single crystal formation after several cycles of melting and freezing, were discussed. The results of measurements along different crystallographic directions for the thermoelectric power, the electrical conductivity, and the thermal conductivity were presented. A thermocouple was also constructed from p- and n-type bismuth telluride single crystals. Without regard to optimization of any parameters, the couple gave a temperature difference of 49°C between the hot and cold ends.

Periodic Impurity Distributions in Horizontally Grown Ge Crystals - See 10,077

10,031 GERMANIUM SATURATED WITH GALLIUM ANTIMONIDE by J. O. McCaldin (Hughes Semicon.) and D. B. Wittry (U. Southern California); J. Appl. Phys., Vol. 32, pp. 65-69, Jan. 1961

The preparation of single crystals of Ge saturated with GaSb by temperature gradient zone melting at 750°C is described. Electron probe microanalysis indicates  $4.83 \times 10^{20}$  Ga atoms and  $2.36 \times 10^{20}$  Sb atoms/cc in the saturated material with an estimated error of about 10 per cent. Thus the solubility of Sb is greatly enhanced by the presence of Ga, though the reverse is not true. Hall measurements are in semiquantitative agreement



## CRYSTAL GROWTH (Cont'd)

with the chemical concentration measurements and indicate that carrier mobility is not much affected by the presence of the compensating impurity.

Growth of Silver Halide Crystals by Zone Melting - See 10,015

10,032 PREPARATION AND PROPERTIES OF  $\text{CdSnAs}_2$  by A. J. Strauss and A. J. Rosenberg (Lincoln Lab.); J. Phys. Chem. Solids, Vol. 17, pp. 278-283, Jan. 1961

The preparation of n-type samples of  $\text{CdSnAs}_2$  (melting point =  $590^\circ - 600^\circ\text{C}$ ) by freezing from the melt is described. The highest room temperature Hall mobility attained was  $1.2 \times 10^4 \text{ cm}^2/\text{volt sec}$  for a sample with a free electron concentration of  $5.5 \times 10^{17} \text{ cm}^{-3}$ . From infrared absorption data the energy gap is estimated to be approximately 0.23 eV at room temperature. The absorption edge shifts to shorter wavelengths with increasing electron concentration. The electrical and optical data indicate that the conduction band of  $\text{CdSnAs}_2$  is characterized by a low electron effective mass, of the order of a few hundredths of the free electron mass.

10,033 VAPOR PHASE GROWTH AND PROPERTIES OF ZINC SULFIDE SINGLE CRYSTALS by H. Samelson (Genl. Tel. Electronics); J. Appl. Phys., Vol. 32, pp. 309-317, Feb. 1961

The growth of zinc sulfide single crystals by a sealed tube vapor phase method is described. In this system the parameters that are studied are the evaporation temperature, the temperature schedule during a run, the temperature gradient along the length of the tube, and, finally, the ambient pressure of  $\text{H}_2\text{S}$  in the tube. The resulting crystals are of a rodlike, distorted rodlike, or platelike habit, and the dominant habit, in any given run, is responsive to variations in the experimental parameters. An altogether different habit is observed in runs performed in a vacuum. The structure of the crystals varies from pure hexagonal to reversed cubic; most of the crystals exhibit stacking faults to various degrees. The structure is a function of the growth temperature. For crystals grown in an  $\text{H}_2\text{S}$  ambient, the mechanism proposed is an initial growth of a fine rod followed by a thickening of the rod and its possible subsequent development into a plate. The whisker growth is probably not a nucleation process and may proceed by a screw dislocation or stepped plane mechanism. The subsequent steps, as well as the growth of crystals in a vacuum, are consistent with a surface nucleation mechanism.

10,034 GROWTH FROM THE VAPOR OF LARGE SINGLE CRYSTALS OF LEAD SELENIDE OF CONTROLLED COMPOSITION by A. C. Prior (RRE); J. Electrochem. Soc., Vol. 108, pp. 82-87, Jan. 1961

The growth of lead selenide crystals by sublimation using a technique in which charges of a few grams are frequently converted almost completely into single crystals is described. A substantial measure of control of the Pb:Se ratio of the resulting crystals is achieved by independent control of the partial vapor pressure of selenium during growth, giving carrier concentrations more than an order lower than has been achieved in crystals grown from the melt.

10,035 METHOD OF MEASURING AND CONTROLLING EVAPORATION RATES DURING THE PRODUCTION OF THIN FILMS IN VACUUM by H. Schwarz (RCA); Rev. Sci. Instr.,

Vol. 32, pp. 194-199, Jan. 1961

A method and device for measuring the density in a vapor stream of any material to be deposited on a suitable substrate in vacuum are described. For this purpose a "nude" ionization gauge is used. The new ionization method differs from others in that it discriminates between the ions of the vapor and those resulting from the background pressure in the vacuum system. The ionization gauge is placed over a hole in the substrate holder; this hole is periodically opened and closed by a shutter vibrating at a low frequency, so that the ion gauge receives a pulsed vapor stream and detects an alternating ion current of the frequency of the shutter vibrator. A current integrator may control the total amount of evaporated material. The ionization gauge used in this method can easily measure the total pressure when the filtering system is bypassed. Calibration curves are shown and a theory is given. Sensitivities of the order of 1 A/sec and lower have been obtained.

10,036 THE SYNTHESIS, STRUCTURE, AND THERMOELECTRIC PROPERTIES OF SOME II-IV COMPOUNDS by V. A. Russell and P. H. Klein (GE); Symp. Thermoelectric Energy Conversion, Jan. 1961

The preparation, crystal structure, and thermoelectric properties of compounds of alkaline-earth metals with silicon, tin, and lead were discussed. Because of the reactivity of the alkaline-earth metals and their high vapor pressures at the temperatures for synthesis, special handling techniques have been evolved. X-ray data show slight deviations from a cubic structure, in most cases, in agreement with the sparse published structural information. Measurement of the thermoelectric properties required the development of suitable encapsulation techniques and the affixing of electrical connections by a modified percussion-welding technique. The available data was reviewed and correlated with the chemical composition of these substances.

Growth of Single Crystals of  $\text{TiSe}$  - See 10,091

Oil Free, Ultra-High Vacuum System for Depositing Sn Films - See 10,082

10,037 SYNTHESIS AND PROPERTIES OF THE SAMARIUM SULFIDES by M. D. Houston (Westinghouse Res. Lab.); Symp. Thermoelectric Energy Conversion, Jan. 1961

The properties of samarium sulfides synthesized by direct reaction of the elements in sealed quartz chambers at temperatures in the range  $600^\circ$  to  $800^\circ\text{C}$  were discussed. Thermoelectric and x-ray structure data have been obtained on polycrystalline compacts or powders. The analysis of the Sm-S system established four definite compounds,  $\text{SmS}$ ,  $\text{Sm}_3\text{S}_4$ ,  $\text{Sm}_2\text{S}_3$  and  $\text{SmS}_2$ , all cubic, and a solid solution series from  $\text{Sm}_3\text{S}_4$  to  $\text{Sm}_2\text{S}_3$ . This binary is analogous to that reported for Ce-S and probably applies to most of the rare earth-sulfur systems. The electrical characteristics change from insulating to semiconducting as the samarium/sulfur ratio increases. One mixed valence compound,  $\text{Sm}^{\text{II}}\text{Sm}_2^{\text{III}}\text{S}_4$ , is suggested by the magnetic susceptibility data and the conditions for electroneutrality in the crystalline structure. All compounds possess melting points in excess of  $1500^\circ\text{C}$ . Semiconducting compounds have thermal conductivities of  $10^{-2} \text{ watts}/^\circ\text{C-cm}$  and good thermoelectric characteristics up to  $1000^\circ\text{C}$ . Precautionary measures to prevent oxidation must be applied when utilizing the material at high temperatures.



## CRYSTAL GROWTH (Cont'd)

10,038 STUDY OF THE INFLUENCE OF ATMOSPHERE AND ANNEALING ON CRYSTAL GROWTH PERFORMED WITH ELECTRICALLY SUSTAINED HEAT SOURCE by A. J. Marino and W. L. Harries (ITT Labs.); U.S. Gov. Res. Rep., Vol. 35, pp. 110-111 (A), Jan. 13, 1961 PB 150 547

An investigation of the various parameters of the flame fusion technique, the effects of impurities, techniques for further heating the crystals after growth, and the design of processes to produce more perfect crystals is described.

10,039 EFFECT OF BORON ON SQUARE-LOOP CADMIUM MANGANESE FERRITES by B. R. Eichbaum (Ford Motor); Am. Ceram. Soc., Vol. 44, pp. 51-54, Feb. 1961

In semiconductor fabrication it is common practice to use a grain-growth promoter with pure germanium or silicon with very small quantities (parts per million) of a promoting agent (such as boron or phosphorus) to obtain the desired semiconducting properties. Several materials such as antimony, boron, lead, lithium, potassium, and sodium have been investigated as possible agents for the promotion of grain growth in cadmium manganese ferrites. It was noted that the characteristics of ferrites could be affected by treating with these agents before sintering. The boron additions to these ferrites accelerated the reaction rates (catalytic action) and affected the characteristics during sintering. The methods of preparation and the observed results are discussed.

10,040 STEP FORMATION DURING THE GROWTH OF  $\text{BaTiO}_3$  CRYSTALS by R. C. DeVries and G. W. Sears (GE Res. Lab.); J. Chem. Phys., Vol. 34, pp. 616-618, Feb. 1961

The growth behavior of barium titanate crystals from molten potassium fluoride at  $1000^\circ\text{C}$  may be described in some detail by the Frank growth mechanism. In particular the role of re-entrant twin angles as growth step sources is examined. A finite supersaturation is required for the operation of this source and the event must occur by an easier nucleation process than homogeneous two-dimensional nucleation.

## CRYSTAL SURFACES

10,041 IRON WHISKER SURFACE REARRANGEMENTS RESULTING FROM THE HYDROGEN REDUCTION OF OXIDES AND FROM THERMAL ETCHING by J. V. Laukonis (GM Res. Labs.) and R. V. Coleman (U. Illinois); J. Appl. Phys., Vol. 32, pp. 242-247, Feb. 1961

The hydrogen reduction of high-temperature oxidation products grown on iron whiskers produces iron surfaces whose topography depends on the orientation of the surface that was oxidized. The different topographies for (100) and (110) surfaces are shown, and the dependence is further illustrated on the polycrystalline iron surfaces which result from the heating of a single-crystal iron whisker through its transformation temperature of  $910^\circ\text{C}$ . Rearranged surfaces covered with parallel striations and unusual dendritic surface structures are shown and discussed. Both the striations and dendrites are the result of thermal etching of a "polycrystalline" iron whisker at temperatures between  $800^\circ - 1200^\circ\text{C}$ .

Adsorption of Gases on Crystals with the Diamond Structure - See 10,028

10,042 ELECTROLYTE SLICES SEMICONDUCTOR CRYSTALS by R. A. Peak (Raytheon); Electronics, Vol. 34, pp. 82-84, Jan. 20, 1961

Electrolytic slice etching of germanium crystal, which can cut wafers as thin as  $0.0005''$  with no mechanical surface damage, is described. Kerfs are  $0.014''$  at maximum cutting rates (1.5 in per hr). A stainless steel jet stream is forced down a three mil tungsten cutting cathode (wire) with the crystal as the anode. The wire provides a current path while the stream serves as etchant and coolant and sweeps out of the active region the reaction products and gas bubbles formed at the wire. A 0.0015 per cent regulated voltage supply minimizes dc fluctuation. Specimen movement is accomplished by a direct drive system. Side cutting is held constant by a constant ratio between current density and forward velocity of the anode.

10,043 ELECTROLYTIC POLISH FOR LEAD TELLURIDE by P. H. Schmidt (Bell Labs.); J. Electrochem. Soc., Vol. 108, pp. 104-105, Jan. 1961

A technique for electrolytically polishing all crystallographic planes in lead telluride is described. The surface of the sample is abraded, cleaned with benzene, and preheated at  $70^\circ\text{C}$  in a drying oven. The electropolishing is performed immediately after the sample is removed from the drying oven. The sample is continually agitated while the current density of about  $3\text{a}/\text{cm}^2$  flows. The electrolyte consisting of a mixture of 100 ml of reagent grade 85 per cent phosphoric acid and 10g reagent grade chromic acid must be kept at  $90^\circ - 105^\circ\text{C}$ . A warm water ( $70^\circ\text{C}$ ) rinse removes the electrolyte and an air jet is used to dry the sample. The method produces "mirror-like" polished surfaces having no macroscopic defects or waves.

10,044 ETCH PITS AT DISLOCATIONS IN COPPER by F. W. Young, Jr. (Oak Ridge Natl. Lab.); J. Appl. Phys., Vol. 32, pp. 192-201, Feb. 1961

A possible mechanism for the development of etch pits at dislocations in copper by etching in solution is proposed, and experiments which may substantiate this mechanism are described. Formulas for etchants which will develop pits at clean dislocations on the (111), (100), and (110) faces of copper are given. These etchants are capable of distinguishing between clean dislocations and dislocations with a "Cottrell atmosphere" in 99.999% copper. Clean edge and screw dislocations can also be differentiated with these etchants. Some observations concerning the relation of facet structure, developed by etching, to the dislocation structure of the crystal are reported.

10,045 DISLOCATION ETCH PITS ON BISMUTH TELLURIDE CRYSTALS by I. Teramoto and S. Takayanagi (Matsushita Electronics); J. Appl. Phys., Vol. 32, pp. 119-120 (L), Jan. 1961

The production of both hexagonal and triangular dislocation etch pits on cleaned surfaces of bismuth telluride is discussed. A solution consisting of either 30 per cent  $\text{HNO}_3$  or two parts  $\text{HNO}_3$ , one part  $\text{HCl}$ , and six parts  $\text{H}_2\text{O}$  produces hexagonal pits at room temperature. The pits exhibit alternate long and short sides. Triangular etch pits can be produced by a solution consisting of 10ml of  $\text{HNO}_3$ , 10 ml of  $\text{HCl}$ , 40 ml of  $\text{H}_2\text{O}$ , and 1g of iodine. It was observed that triangular etch pits can be produced in crystals doped with iodine even though the etch does not contain iodine and that hexagonal pits become triangular when the surface is etched in a solution containing iodine.



## CRYSTAL SURFACES (Cont'd)

Dislocation Etch Pits in Tellurium - See 10,011

10,046 ETCH PITS IN PYROLYTIC GRAPHITE by A. Tarpinian and G. E. Gazza (Watertown Arsenal Labs.); U. S. Gov. Res. Rep., Vol. 35, p. 91 (A), Jan. 13, 1961 PB 150 917

The observation of pits in pyrolytic graphic after ion bombardment etching is described and their similarity to dislocation etch pits is considered. Evidence of etch pit multiplication in the form of slip line segments and low angle tilt boundaries is presented.

Surface Cleaning by Ion Bombardment - See 10,052

10,047 ACTIVE-METAL SOLDERING OF CRYSTALLINE QUARTZ by M. E. Knoll (GE); Rev. Sci. Instr., Vol. 32, p. 83, Jan. 1961

It is reported that very strong hermetic seals can be made to quartz crystals using a hydride of titanium or zirconium and a solder composed of copper-bearing lead or indium.

10,048 SPUTTERING OF SILICON WITH  $A^{+2}$  IONS by S. P. Wolsky and E. J. Zdanuk (Raytheon); Phys. Rev., Vol. 121, pp. 374-375, Jan. 15, 1961

A gravimetric technique involving a sensitive quartz microbalance which has been used for the determination of sputtering yields for the argon ion-bombardment of silicon is described. The sputtering yield for  $A^{+2}$  ions was deduced from the results of experiments in which the relative concentrations of  $A^{+}$  and  $A^{+2}$  ions were varied in a known manner. On the assumption that sputtering is a kinetic-energy-controlled phenomenon, one would expect  $S_E(A^{+2}) = S_E(A^{+})$ , where  $S$  is the number of atoms sputtered by an impinging ion of energy  $E$ . Investigation showed, however, that  $S_E(A^{+2}) \approx 4S_E(A^{+})$ . This indicates the influence in the sputtering process of some other factor in addition to the ion kinetic energy.

10,049 SPUTTERING OF VITREOUS SILICA BY 20- TO 60-KEV  $Xe^{+}$  IONS by R. L. Hines and R. Wallor (Northwestern U.); J. Appl. Phys., Vol. 32, pp. 202-204, Feb. 1961

Experimental values for the sputtering of quartz by xenon positive ions at flux densities of  $2 \times 10^{15}$  ions/cm<sup>2</sup>sec in a vacuum of  $10^{-5}$  mm Hg, found by measuring the volume of the sputtered cavity by means of interference fringe contours, are reported. The sputtering ratios are  $0.706 \pm 0.061$  at 20 keV,  $0.85 \pm 0.13$  at 30 keV,  $1.78 \pm 0.13$  at 40 keV,  $1.74 \pm 0.12$  at 50 keV, and  $1.31 \pm 0.09$  at 60 keV. The technique of volume measurement by interference fringe contours has an accuracy of  $\pm 2 \times 10^{-8}$  cc and is estimated to have an ultimate accuracy of  $\pm 10^{-10}$  cc.

## RADIATION EFFECTS

10,050 ENERGY DEPENDENCE OF RADIATION DAMAGE IN TUNGSTEN by D. R. Muss and J. R. Townsend (U. Pittsburgh); J. Appl. Phys., Vol. 32, pp. 189-192, Feb. 1961

The rate of radiation damage in tungsten is shown experimentally to depend on the energy of the incident deuterons almost as  $1/E$ . The small deviation from the  $1/E$  dependence is in a

direction opposite to that predicted by the hard sphere model for secondary defect production.

10,051 RADIATION DEFECTS IN CRYSTALS by L. S. Smirnov (P. N. Lebedev Phys. Inst.); Soviet Phys.-Solid State, Vol. 2, pp. 1512-1513, Jan. 1961

The formation, structure, and restoration of radiation defects in crystals is discussed. Energy of impact is transferred from the primary excited atom to other atoms nearby, permitting their movement due to localized melting. A defect is established if order is not restored in the melted region upon its hardening. The possibility of such an occurrence in silicon and germanium is theorized. In germanium, an approximate calculation indicates that 26 atoms will be contained in the minimum volume of the localized melted region in which reordering is possible, upon subsequent thermal oscillations.

Radiation-Induced Defects in Si - See 10,111 and 10,120

10,052 INFLUENCE OF TEMPERATURE AND BOMBARDMENT RATE ON DISORIENTATION OF SILVER SINGLE CRYSTALS BY ION BOMBARDMENT by G. J. Ogilvie and A. A. Thomson (CSIRO); J. Phys. Chem. Solids, Vol. 17, pp. 203-209, Jan. 1961

Results of bombarding single crystals of silver with (110), (001), and (111) planes parallel to the surface, by positive ions of argon having an energy of 130 eV at constant temperatures in the range  $100^{\circ}$  -  $400^{\circ}$  C are reported. Transmission electron diffraction patterns obtained from thinned regions in the crystals show that disoriented crystallites and stacking disorders are caused by the bombardment. The effects due to disoriented crystallites decrease in intensity as the temperature of bombardment increases. It is shown that the disorientation increases with increasing current density of ions and the change in disorientation with annealing is studied. The application of the results to the problem of producing clean surfaces by ion bombardment is discussed. It is shown that thermal annealing is not sufficient to account for the change in disorientation with bombardment temperature. The possibility that point defects introduced by bombardment accelerate annealing is examined.

Neutron Irradiation of Cu - See 10,148

Doping Si by Neutron Bombardment - See 10,021

Electron Bombardment of Ge - See 10,076

10,053 HIGH-ENERGY RADIATION DAMAGE TO FLUORESCENT ORGANIC SOLIDS by C. F. Sharn (U.S. Naval Res. Lab.); J. Chem. Phys., Vol. 34, pp. 240-246, Jan. 1961

A study of radiation damage to organic solids exposed to  $Co^{60}$  gamma rays by an analysis of the induced fluorescent changes is reported. From the fluorescence degradation for two series of aromatic hydro-carbons, correlations between chemical structure and radiation damage have been established. In addition, modifications in a conventional model used to describe the fluorescent degradation mechanism in organic materials are suggested by the data. Some of the organic materials studied have potential application in a dosimetry system based on fluorescence degradation.



# SOLID STATE PHYSICS

## GENERAL

10,054 PHYSICAL PROPERTIES OF SEVERAL II-V SEMICONDUCTORS by W. J. Turner, A. S. Fischler, and W. E. Reese (IBM); Phys. Rev., Vol. 121, pp. 759-767, Feb. 1, 1961

The physical properties of single crystals of the noncubic II-V semiconducting compounds  $\text{Zn}_3\text{As}_2$ ,  $\text{ZnAs}_2$ ,  $\text{ZnSb}$ ,  $\text{Cd}_3\text{As}_2$ ,  $\text{CdAs}_2$ , and  $\text{CdSb}$  are discussed. Energy gaps in these materials vary from approximately 0.13 to 1.0 eV. Mobilities at 297°K range from 10 cm<sup>2</sup>/volt sec to 15 000 cm<sup>2</sup>/volt sec and increase at low temperature. Resistivity and mobility anisotropy have been investigated in detail for  $\text{CdAs}_2$ . Except for the  $\text{A}_3\text{B}_2\text{V}$  compounds, high optical transmission has been observed from the intrinsic edge to approximately 30 microns.

## CRYSTAL PHYSICS

(including Energy Band Structure)

10,055 SOLUTION OF THE FUNCTIONAL DIFFERENTIAL EQUATION FOR THE STATISTICAL EQUILIBRIUM OF A CRYSTAL by R. M. Lewis and J. B. Keller (New York U.); Phys. Rev., Vol. 121, pp. 1022-1037, Feb. 15, 1961

The s-particle distribution functions ( $s=1, 2, \dots$ ) of classical equilibrium statistical mechanics are determined for a crystal, as power series in the temperature, by solving Bogolyubov's functional differential equation. From the distribution functions, the thermodynamic functions of a crystal are computed as power series in the temperature. The leading terms in these series are the usual classical results which are customarily derived by assuming that the potential energy is a quadratic function of the particle displacements. The further terms, which depend upon the nonquadratic or anharmonic terms in the potential, provide corrections to the usual results, which become more important as the temperature increases. If only a few terms in the series are used, the results will be valid at temperatures low compared to some characteristic temperature of the crystal, e.g., the melting temperature. Since they are based on classical mechanics, the results are valid only at temperatures high compared to the Debye temperature. The series expansions of the distribution functions and thermodynamic functions may be viewed as the low-temperature analogs of the virial expansions, which are low-density expansions. As in the case of the virial expansions, all the terms are determined explicitly in analytic form, but their actual evaluation is difficult.

10,056 ENERGY BANDS IN THE BISMUTH STRUCTURE. I. A NONELLIPSOIDAL MODEL FOR ELECTRONS IN Bi by M. H. Cohen (U. Chicago and Hughes Res. Labs.); Phys. Rev., Vol. 121, pp. 387-395, Jan. 15, 1961

The band structure near a minimum at a point of no special symmetry is examined for energies small compared to all band gaps except that to the next lower band. Spin-orbit coupling is included. The theory is specialized to points having the

three possible symmetries of electrons in Bi and further simplifications appropriate to Bi are made. The resulting non-ellipsoidal energy surfaces are studied in some detail. An experiment which is capable of distinguishing between the three possibilities is suggested.

Conduction Bands of InAs and GaAs - See 10,068

Conduction Band of GaSb - See 10,073

10,057 INTERACTION OF A POLARIZABLE POTASSIUM CHLORIDE CRYSTAL WITH A VALENCE-BAND HOLE by S. J. Nettel (MIT); Phys. Rev., Vol. 121, pp. 425-435, Jan. 15, 1961

The interaction of a valence-band hole with a potassium chloride crystal considering crystal-hole correlations is studied by variational means. Initially a crystal trial wave function is constructed which allows for the ionic polarizability of the crystal by means of a correlation between the crystal configuration and the motion of the hole. The expectation value of the Hamiltonian operator for the crystal is found by integrating over both electronic and nuclear coordinates. The necessary matrix elements of the electronic energy operators are taken from a previous calculation by Howland. The total energy expectation is minimized with respect to a single parameter in the wave function that measures the hole-lattice correlation. One finds that the valence bands obtained when the crystal lattice is treated as rigid become completely flat, a result which implies that the hole is self-trapped. The modifications that are introduced by the addition of the electronic polarizability are studied by repeating the previous calculation with a refined wave function. Only a rough treatment drawing on the experimental electronic polarizabilities of the crystal ions is given. Information on self-trapped holes in KCl derived from the electron-spin resonance experiments of Castner and Känzig is briefly considered.

Energy Gaps of II-V Compounds - See 10,054

Energy Gap of  $\text{Ag}_2\text{Te}$  - See 10,061

Energy Gap of  $\text{MnAl}_3$  - See 10,145

Energy Gap of  $\text{CdSnAs}_2$  - See 10,032

Donor Levels in InSb - See 10,066

Impurity Levels in MgO - See 10,085

Energy Band Structure of Te - See 10,094

Energy Band Structure of Cu-Ge Alloys - See 10,122

10,058 NATURE OF VIBRATIONAL MODES IN IONIC CRYSTALS by H. B. Rosenstock (U.S. Naval Res. Lab.); Phys. Rev., Vol. 121, pp. 416-424, Jan. 15, 1961

The characteristics of vibration modes in a solid are discussed. It is concluded that: (1) Waves in lattices are in general neither transverse nor longitudinal; in particular they need not be transverse or longitudinal when the propagation vector  $k$  is very small. (2) The relationship  $\omega_1/\omega_t = (\epsilon_0/\epsilon_\infty)^{1/2}$  for "longitudinal" and "transverse" modes in ionic crystals applies, if at all,



in a region of small, but nonzero, wave vector  $k$ . (3) The derivation of this relationship is based, at least implicitly, on the use of cyclic boundary conditions. (4) The use of cyclic boundary conditions is valid in statistical problems for crystals without long-range forces, but has never been justified for systems with Coulomb forces. (5) If cyclic boundary conditions are nonetheless used, it can be simply shown that for  $k = 0$ ,  $\omega_l/\omega_t = 1$ .

Electronic Structure of Luminescent Centers - See 10,126

## ELECTRICAL PROPERTIES - GENERAL

10,059 NUCLEAR QUADRUPOLE SPIN-LATTICE RELAXATION IN SOLIDS by M. J. Weber (U. California); J. Phys. Chem. Solids, Vol. 17, pp. 267-277, Jan. 1961

Measurements of nuclear quadrupole spin-lattice relaxation in solids using pulsed nuclear induction techniques are reported. By selective excitation of the quadrupolar spin system, several new modes of relaxation have been observed. Measurements of these modes are used to determine the individual transition probabilities  $W_1$  and  $W_2$  associated with  $\Delta m = \pm 1$  and  $\pm 2$  quadrupole spin-lattice relaxation.  $W_1$ ,  $W_2$ , and the spin-lattice relaxation time  $T_1$  of the  $\text{Cl}^{35}$  pure quadrupole resonance in  $p\text{-C}_6\text{H}_4\text{Cl}_2$ ,  $\text{KClO}_3$ , and  $\text{NaClO}_3$  have been measured in the temperature range  $77^\circ\text{--}300^\circ\text{K}$ . The Bayer theory of quadrupole spin-lattice relaxation is applied to  $p\text{-C}_6\text{H}_4\text{Cl}_2$  to calculate  $W_1$  and  $W_2$ . From the Bayer theory and the separate measurement of  $W_1$  and  $W_2$ , information is obtained about the lifetime of excited torsional states and the mode of torsional oscillation which provides the dominant relaxation contribution in  $p\text{-C}_6\text{H}_4\text{Cl}_2$ . Measurements of the spin-lattice relaxation in  $\text{NaClO}_3$  and  $\text{KClO}_3$  are compared with Chang's theory of quadrupole relaxation. The experimental results suggest that the model used by Chang to describe the fluctuating internal electric field gradient in  $\text{NaClO}_3$  responsible for the  $\text{Cl}^{35}$  relaxation is inadequate.

10,060 TEMPERATURE DEPENDENCE OF THE NUCLEAR QUADRUPOLE SPECTRUM OF  $\text{Nb}^{93}$  IN FERROELECTRIC  $\text{KNbO}_3$  by R. E. Hewitt (U. California); Phys. Rev., Vol. 121, pp. 45-52, Jan. 1, 1961

Measurements of the nuclear electric quadrupole interaction of  $\text{Nb}^{93}$  in ferroelectric  $\text{KNbO}_3$  as a function of temperature in the tetragonal, orthorhombic and rhombohedral phases are reported. The values of  $(1/\nu)(d\nu/dT)$  for these three phases are approximately  $-10^{-3}$ ,  $-10^{-3}$ , and  $-10^{-4}$  per degree centigrade, respectively. In the tetragonal phase at  $220^\circ\text{C}$   $e^2qQ/h$  has been measured as 24 Mc/sec and the asymmetry parameter  $\eta$  is zero. An ionic calculation of field gradients in the tetragonal phase has been made including point charge and induced dipole contributions. The results of this calculation give the Sternheimer antishielding factor  $(1-\gamma_\infty)$  as 15, in good agreement with its estimated value of +16. The temperature dependence of the electric field gradient at the  $\text{Nb}^{93}$  site as calculated from this ionic model is in agreement with the measured temperature dependence in the tetragonal phase.

Measurement of Carrier Properties by the Photo-Hall Effect - See 10,070

Energy Distributions of Hot Electrons, Holes, and Excitons in Si - See 10,125

Excitons and Plasmons in Superconductors - See 10,079

Diffusion of Excitons - See 10,136

10,061 DEGENERACY IN  $\text{Ag}_2\text{Te}$  by C. Wood, V. Harapp and W. M. Kane (Philco); Phys. Rev., Vol. 121, pp. 978-982, Feb. 15, 1961

Measurements of the Hall coefficient, resistivity, and Seebeck coefficient of  $n$ - and  $p$ -type specimens of  $\text{Ag}_2\text{Te}$  over the temperature range from  $55^\circ$  to  $300^\circ\text{K}$  are reported. These results indicate that the compound is highly degenerate over the whole temperature range studied. Order of magnitude calculations of the effective masses, mobility ratios, and energy gap are given.

Diffusion Lengths for Carriers in the Regrown Region of Alloyed Junctions - See 10,176

10,062 DECAY OF EXCESS CARRIERS IN SEMICONDUCTORS. II by K. C. Nomura and J. S. Blakemore (Honeywell Res. Ctr.); Phys. Rev., Vol. 121, pp. 734-740, Feb. 1, 1961

A physical interpretation of the nonlinear differential equations which govern the decay of excess carrier populations through recombination centers is given. No restrictions are placed on the magnitudes of the excess carrier densities or the center density. Criteria for trapping are presented; with semiconductors for which the trapping level lies in the opposite half of the intrinsic gap from the Fermi level, it is shown that trapping can be described as being of either a temporary or permanent nature. The variety of possible modes of decay are illustrated with the aid of numerical solutions and approximate analytic solutions.

10,063 RADIO-FREQUENCY CARRIER AND CAPACITIVE COUPLING PROCEDURES FOR RESISTIVITY AND LIFETIME MEASUREMENTS ON SILICON by I. R. Weingarten and M. Rothberg (Merck Sharp and Dohme); J. Electrochem. Soc., Vol. 108, p. 167, Feb. 1961

Use of a radio-frequency carrier and capacitive coupling to measure the resistance and lifetime of silicon rods without making direct ohmic contact to the samples is described. Even with contacts, the use of an RF carrier to observe lifetime by photoconduction decay eliminates the need for insuring solid ohmic contacts as is required with a d-c carrier. With low loss insulation between coupling capacitors and the sample, an RF bridge will measure separately both the sample resistance between the coupling capacitors and the value of this coupling capacitance.

10,064 RECOMBINATION OF ELECTRONS AND HOLES ON ATOMS OF COPPER AND NICKEL IN HIGH-RESISTANCE GERMANIUM by V. V. Rybalka and A. S. Pizio (L'vov State U.); Soviet Phys.-Solid State, Vol. 2, pp. 1604-1605, Feb. 1961

The temperature dependence of lifetime in high resistance  $n$ -type Ge when alloyed with either Cu or Ni as impurities is



## CARRIER PROPERTIES (Cont'd)

evaluated. Recombination rates were determined in the temperature range from 150° to 300°K, using both the pulse and photoconductivity decay method. Lifetime decreases exponentially with temperature for samples with the Ni impurity, while lifetime increases exponentially with temperature for samples with the Cu impurity. Experimental results agree well with those predicted by the theoretical expression derived.

10,065 EFFECT OF LINEAR DISLOCATIONS ON CARRIER RECOMBINATION IN HOLE CONDUCTING GERMANIUM by M. I. Iglitsyn and L. I. Kolesnik; Soviet Phys.-Solid State, Vol. 2, pp. 1400-1401, Jan. 1961

Qualitative relationships characterizing recombination at dislocations are discussed. Plastic deformation was used to obtain linear dislocations which were, as far as possible, unrelated to impurities. The hyperbolic dependence of minority carrier lifetime on dislocation density, measured at room temperature, indicates that each linear dislocation acts as a recombination center. Lifetime is plotted as a function of temperature; saturation (zero slope) at low temperatures was not observed. The product of lifetime and unit dislocation length is plotted as a function of temperature; the slope corresponds to an activation energy of 0.14 eV.

10,066 CARRIER LIFETIME IN INDIUM ANTIMONIDE by R. L. Laff and H. Y. Fan (Purdue U.); Phys. Rev., Vol. 121, pp. 13-62, Jan. 1, 1961

The recombination of excess electron-hole pairs in indium antimonide in the temperature range 200°K-15°K, where it is controlled by localized centers, is discussed. Minority carrier trapping is found in extrinsic p-type material. The lifetimes of electrons and holes obtained from photoconductivity and photoelectromagnetic effect data on n- and p-type samples lead to a model for the recombination, consisting of a donor center having two energy levels in the forbidden gap, at 0.055 and 0.12 eV above the valence band. The capture coefficients for holes and electrons have been determined for the center in each of the two charge states. In p-type material, the chemical acceptors are in statistical equilibrium with the free holes in the valence band. When holes freeze out onto acceptor centers ( $T < 60^\circ\text{K}$ ), an increase of free holes due to photoexcitation leads to a corresponding increase in the hole concentration on the acceptors. This effect of majority carrier trapping reduces the rise of hole lifetime with decreasing hole concentration. In order to determine the nature of the recombination centers, different treatments have been used to introduce additional centers. It has been found that bombardment with 4.5 MeV electrons produces additional centers having the same recombination properties as the original centers. The result indicates that the recombination centers have the nature of structural defects rather than chemical impurities.

10,067 Hole Capture Cross Section in Au-Doped Ge - See 10,132

10,068 Capture Cross-Sections of Ionized F-Centers - See 10,139

10,067 COMPARATIVE INVESTIGATION OF MAGNETOCONCENTRATION AND PHOTOELECTRIC METHODS OF MEASURING THE SURFACE RECOMBINATION RATE by O. V. Sorokin and B. T. Tuseev (Inst. Semicon., Leningrad); Soviet Phys.-Solid State, Vol. 2, pp. 1391-1393, Jan. 1961

The surface recombination rate resulting from application and removal of an external d-c electric field is evaluated. Three

different methods of measurement were used, involving (a) the d-c component of voltage of the magnetoconcentration effect, (b) the voltage of the second harmonic of the magnetoconcentration effect, and (c) the "traveling light beam." Comparison of test results on single-crystal n-type germanium indicates that the magnetoconcentration effect method provides a true measurement of surface recombination rate.

Recombination in AgCl Crystals - See 10,133

10,068 ELECTRON EFFECTIVE MASSES OF InAs AND GaAs AS A FUNCTION OF TEMPERATURE AND DOPING by M. Cardona (RCA Labs. Zurich); Phys. Rev., Vol. 121, pp. 752-758, Feb. 1, 1961

Values of the electron effective masses of several GaAs and InAs samples at room and liquid nitrogen temperatures, determined from Faraday rotation and infrared reflectivity measurements, are reported. An increase in effective mass with increasing carrier concentration has been found in both materials. This increase can be quantitatively interpreted in InAs in terms of the nonparabolic nature of the conduction band. In GaAs the increase in effective mass with doping suggests the existence of another set of conduction band minima above the lowest (000) minimum. The measured temperature variation of the effective mass can be attributed to two mechanisms: the increase in effective mass produced by the spread in the Fermi distribution because of the nonparabolic shape of the band, and the variation in the band structure produced by the thermal expansion of the lattice. The Faraday rotation due to the interband transitions has been measured in GaAs and InAs. This rotation is clockwise along the direction of motion of the radiation and the magnetic field for GaAs and counterclockwise for InAs. This effect is compared with the corresponding effect in other semiconductors.

10,069 ELECTROMAGNETIC PROPERTIES OF INSULATORS. II by V. Ambegaokar (Carnegie Inst. Tech. and Westinghouse); Phys. Rev., Vol. 121, pp. 91-103, Jan. 1, 1961

The electromagnetic properties of insulators are studied from a many particle point of view, the system of an insulator and one electron being treated. The Coulomb interactions between all the electrons in the system are allowed for to all orders of perturbation theory. The true effective mass  $m^*$  of the extra particle is defined as the curvature in wave vector space of the energy surface connecting the ground state and the low-lying excited states of the interacting system. The central result then obtained is that the response of the system to long-wavelength, low-frequency electric fields is exactly that of a free electron of mass  $m^*$  moving in a medium characterized by the dielectric constant of the perfect insulator. The energy levels of the system in a static magnetic field are also discussed. An alternative derivation of a single-particle effective-mass equation, previously obtained by Klein, is given. The eigenvalues of this equation are under certain conditions the energy levels of the interacting system in a magnetic field. In an Appendix a Kramers-Kronig relation connecting the difference in optical absorption of the present system and the perfect insulator with  $m^*$  is derived. These results indicate that the usual effective-mass theory of semiconductors of low carrier concentration includes the effects of the electron-electron interactions to an excellent approximation.

Effective Mass in Te - See 10,094

Effective Mass in Na - See 10,140



## CARRIER PROPERTIES (Cont'd)

Effective Mass in  $\text{Ag}_2\text{Te}$  - See 10,061

Effective Mass in  $\text{Al}_2\text{O}_3$  - See 10,090

Effective Mass in  $\text{CdSnAs}_2$  - See 10,032

10,070 EFFECT OF PHOTOEXCITATION ON THE MOBILITY IN PHOTOCONDUCTING INSULATORS by R. H. Bube and H. E. MacDonald (RCA); Phys. Rev., Vol. 121, pp. 473-483, Jan. 15, 1961

The Hall mobility of carriers in photoconducting insulators can be varied over an appreciable range by the effects of photo-excitation. Such a variation can result either (1) from a change in the density of scattering centers as the result of a change in the occupation of imperfection centers, or (2) from the initiation of two-carrier conductivity. Suitable use of the phenomena involved in the photo-Hall effect can lead not only to knowledge about carrier density, carrier sign, and carrier mobility, but also about the charge on imperfection centers, and to an independent determination of the cross section of imperfection centers. Experiments on  $\text{CdS}$  and  $\text{CdSe}$  single crystals with conductivities lying between  $10^{-9}$  and  $10^{-1}$  mho/cm are described to illustrate the potentialities of the technique. The results emphasize both the importance that changes in mobility can play in normal photoconductive processes, and the importance of hole conductivity under suitable circumstances.

Anomalous Variation of the Electron Mobility in Te-Doped  $\text{GaSb}$  - See 10,073

Effect of Ga and Sb on Carrier Mobility in Ge - See 10,031

Effect of Pressure on Mobility in  $\text{NiO}$ ,  $\text{CoO}$ ,  $\text{CuO}$ , and  $\text{Cu}_2\text{O}$  - See 10,075

Hall Mobility in  $\text{CdSnAs}_2$  - See 10,032

Mobility Ratio in  $\text{Ag}_2\text{Te}$  - See 10,061

Mobility in  $\text{AgCl}$  Crystals - See 10,133

Mobility in  $\text{MnAl}_3$  - See 10,145

Mobility in Alkali Halide Crystals - See 10,139

Mobilities in II-V Compounds - See 10,054

Secondary Ionization in PN Junctions - See 10,163

10,071 VOLUME-CONTROLLED, TWO-CARRIER CURRENTS IN SOLIDS: THE INJECTED PLASMA CASE by M. A. Lampert and A. Rose (RCA); Phys. Rev., Vol. 121, pp. 26-37, Jan. 1, 1961

Double injection into semiconductors and insulators is studied under conditions where the injected electrons and holes are free (injected plasma), the current is volume-controlled, i.e., determined by distributed space charge, and the current is field-driven (diffusion negligible). The major results are, assuming a one-dimensional geometry and carrier lifetime independent of injection level, for extrinsic semiconductors, (i) an extended voltage region over which  $J \propto V^2$  ( $J$  current density and  $V$  voltage), and (ii) depression of the current, at fixed voltage, in the square-law region through increase in the

number of thermal minority carriers,  $J \propto [n_T - p_T]$ , with  $n_T$ ,  $p_T$  the thermal-equilibrium densities of electrons and holes, respectively. This unusual behavior is shown to be a direct consequence of recombination kinetic requirements. For insulators, assuming trapping is negligible,  $J \propto V^3$ . A rigorous solution is obtained for the constant-lifetime problem, valid for both semiconductors and trap-free insulators. This solution furnishes a good approximation also for variable-lifetime cases, e.g., bimolecular recombination kinetics.

## CONDUCTIVITY

10,072 IMPURITY CONDUCTION IN SILICON by R. K. Ray and H. Y. Fan (Purdue U.); Phys. Rev., Vol. 121, pp. 768-779, Feb. 1, 1961

An investigation of impurity conduction at low temperature in various p- and n-type silicon samples is reported. Emphasis was placed on the study of samples of low impurity concentration where the conduction is attributed to charge exchange between impurity centers which are partially ionized by some compensating impurity. A new method was used to determine the compensation. Donors were added to p-type samples by heat treatment. From changes in the room temperature resistivity and the Hall coefficient in the deionization range, the added compensation and the original compensation were determined. The measurement of various samples gave the dependence of the activation energy of conduction on impurity concentration and degree of compensation. The activation energy was much larger for the Ga- and Al-doped samples than for the B-doped samples of comparable impurity concentration. However, it was found that the high activation energies may be the result of ion-pairing between gallium or aluminum atoms and the compensating impurity in the sample. The conductivities of the various samples may be correlated by an expression of conductivity which involves the impurity concentration and the radius of impurity wave function. The results are discussed in the light of current theories of impurity conduction.

10,073 ELECTRICAL PROPERTIES OF N-TYPE  $\text{GaSb}$  by A. J. Strauss (Lincoln Lab.); Phys. Rev., Vol. 121, pp. 1087-1090, Feb. 15, 1961

Measurements of the electrical conductivity and Hall coefficient of n-type  $\text{GaSb}$  doped with Se or Te, in most cases at 77° and 300°K, for samples with net donor concentrations between about  $6 \times 10^{16} \text{ cm}^{-3}$  and  $2 \times 10^{18} \text{ cm}^{-3}$  are reported. In general, the data are consistent with the two-band model which Sagar has proposed for the conduction band of  $\text{GaSb}$ , but systematic differences are observed between the properties of Se-doped and Te-doped samples. It seems likely that these differences are associated with impurity conduction of the metallic type. For the Te-doped samples, the electron mobility at 77°K apparently varies in an anomalous manner with increasing impurity concentration.

10,074 CIRCUIT FOR MEASURING AND RECORDING THE RESISTANCE OF SEMICONDUCTORS IN COORDINATES  $\log R = f(1/T)$  by L. G. Sapogin and V. M. Ivko (Taganrogsk Radiotekh. Inst.); Soviet Phys.-Solid State, Vol. 2, pp. 1346-1351, Jan. 1961

An apparatus for direct measurement of  $\log R = f(1/T)$  is described. The device consists of a combination of a logarithmic and parabolic amplifier which delivers simultaneous signals to an automatic recording device. The signal delivered by the



## CONDUCTIVITY (Cont'd)

logarithmic amplifier is proportional to the logarithm of the resistance, while that delivered by the parabolic amplifier is inversely proportional to the temperature of the semiconductor. A complete schematic and block diagram are presented. This method overcomes disadvantages inherent in the d-c potentiometric probe method.

Carrier and Capacitive Coupling Procedure for Measuring Resistivity - See 10,063

Temperature Dependence of Conductivity in  $\text{MnAl}_3$  - See 10,145

10,075 EFFECT OF HIGH PRESSURE ON ELECTRICAL PROPERTIES OF  $\text{NiO}$ ,  $\text{CoO}$ ,  $\text{CuO}$ , and  $\text{Cu}_2\text{O}$  by A. P. Young, W. J. Wilson, and C. M. Schwartz (Battelle Mem. Inst.); Phys. Rev., Vol. 121, pp. 77-82, Jan. 1, 1961

Measurements of the effect of pressure on electrical resistance and Seebeck coefficient at or near room temperature in  $\text{NiO}$ ,  $\text{CoO}$ ,  $\text{CuO}$ , and  $\text{Cu}_2\text{O}$  are reported. Equations relating the Seebeck coefficient to hole concentration have been used to calculate the effect of pressure on hole mobility. In all materials examined, hole mobility was decreased by pressures to 10 000 atm. It has been proposed that  $\text{NiO}$  charge transport occurs by the motion of holes trapped at local sites by polarization of the surrounding lattice. The effect of pressure on the diffusion of self-trapped holes has been considered. Motion of self-trapped holes in an ionic crystal and of vacancies in a metal may be similar to the extent that the motion of either probably involves cooperative movements of surrounding ions or atoms. Some inward relaxation probably occurs around either a hole trapped at a local site in an ionic crystal or around a vacancy in a metal. In either case pressure would be expected to decrease the jump frequency for motion of the defect. It is proposed that in  $\text{NiO}$ ,  $\text{CoO}$ , and  $\text{CuO}$ , the decreased hole mobility with pressure was due to a decrease in diffusion rate of self-trapped holes. The explanation for pressure effects in  $\text{Cu}_2\text{O}$  may be more complicated since  $\text{Cu}_2\text{O}$  is generally regarded as a wide-band semiconductor.

10,076 EFFECTS OF ELECTRON BOMBARDMENT RATE ON CONDUCTIVITY OF N-TYPE GERMANIUM by R. A. Goldstein (Diamond Ord. Fuze Labs.); U.S. Gov. Res. Rep., Vol. 15, p. 211 (A), Feb. 10, 1961 PB 152 918

An investigation of the effects of electron bombardment rate on the conductivity of n-type germanium crystals is reported. Six samples with initial conductivity of about  $0.8 (\text{ohm-cm})^{-1}$  were irradiated with 4.6 Mev electrons to a total dose of about  $2.5 \times 10^{14}$  electrons/cm<sup>2</sup>, and the change in conductivity was measured as a function of irradiation rate. The decrease in conductivity is shown to be strongly dependent upon the irradiation rate. The carrier removal efficiency, as calculated from the conductivity change after room temperature annealing, was found to increase from 1.77 to 2.34 for irradiation rates of  $0.65 \times 10^{15}$  to  $5.12 \times 10^{16}$  electrons/cm<sup>2</sup>-sec. The irradiated samples were annealed at temperatures up to 215°C. The annealing behavior of all samples was found to be identical, indicating no differences in defect configuration. Six additional samples were irradiated with 1 Mev electrons to a total dose of about  $7.5 \times 10^{14}$  electrons/cm<sup>2</sup>, at irradiation rates of  $0.09 \times 10^{12}$  to  $1.30 \times 10^{15}$  electrons/cm<sup>2</sup>-sec. The carrier removal efficiency was found to be independent of irradiation rate below about  $10^{14}$  electrons/cm<sup>2</sup>-sec. A mechanism to account for the observed rate effect is discussed.

10,077 RESISTIVITY STRIATIONS IN GERMANIUM SINGLE CRYSTALS by H. Ueda (Hitachi, Ltd.); J. Phys. Soc. Japan, Vol. 16, pp. 61-66, Jan. 1961

Observations of resistivity striations resulting from periodic distribution of impurities in single crystals of germanium grown horizontally are reported. The period of the striations ranges from 0.1 to 0.6 mm, depending upon growth conditions. It is proportional to the average growth rate and inversely proportional to the temperature gradient within the crystal near the solid-liquid interface. This relation can be explained by assuming the supercooled state in the course of germanium crystal growth by the zone leveling technique. By the repeated supercooling and recovery from it, the crystallization proceeds periodically, resulting in the periodic change of the transient growth rate and the periodic segregation of impurities.

Preparation of Uniform Resistivity in Si by Nuclear Transmutation - See 10,021

Resistivity of  $\text{Ag}_2\text{Te}$  - See 10,061

## SUPERCONDUCTIVITY

10,078 MAGNETIC FIELD DEPENDENCE OF ENERGY GAP IN SUPERCONDUCTORS by K. K. Gupta and V. S. Mathur (U. Chicago); Phys. Rev., Vol. 121, pp. 107-117, Jan. 1, 1961

The dependence of energy gap in superconductors on static magnetic fields has been derived in a gauge-invariant way from the theory of Bardeen, Cooper, and Schrieffer. It has been shown that the gap width decreases with magnetic field approaching the critical value. Optimum conditions have been discussed for the observation of such an effect. The decrease in gap width has been calculated for two superconductors, Al and Sn, and it has been shown that for film thickness between  $10^{-4}$  to  $10^{-5}$  cm, the effect can be large enough to be observable.

Superconducting Solenoid - See 10,211

Heat Capacity of Ferromagnetic Superconductors - See 10,141

Nuclear Magnetic Resonance in Superconducting Tin - See 10,113

10,079 EXCITONS AND PLASMONS IN SUPERCONDUCTORS by A. Bardasis and J. R. Schrieffer (U. Illinois); Phys. Rev., Vol. 121, pp. 1050-1062, Feb. 15, 1961

The Anderson-Rickayzen equations of motion for a superconductor derived within the random-phase approximation (RPA) are used to investigate the collective excitations of superconductors. A spherical harmonic expansion of the two-body interaction potential  $V(k, k')$  is made and a spectrum of excitations whose energies lie within the energy gap  $2\Delta$  is obtained. These excitations may be characterized by the quantum numbers L and M involved in the potential expansion. For an L-state exciton to exist, the L-wave part of the potential must be attractive at the Fermi surface. Odd-L excitons have unit spin and may be considered as spin waves. For s-state pairing in the superconducting ground state, the plasmon mode corresponds to the L = 0 exciton whose energy is strongly modified by the long-range Coulomb interaction. For a general potential several bound states may exist for given L and M. If the L-wave



## SUPERCONDUCTIVITY (Cont'd)

potential is stronger than the s-wave part of the potential, the system is unstable with respect to formation of L-state excitons. In this case, the ground state is formed with L-state pairing, special cases of which are the p-state pairing considered by Fisher and the d-state pairing proposed recently by several authors for the ground state of  $\text{He}^3$  and nuclear matter. Corrections to the Anderson-Richayzen equations which lead to a new set of exciton states if the L-wave potential is repulsive are discussed. These excitons are interpreted as bound electron-hole pairs, as opposed to the particle-particle excitons present with an attractive L-wave potential.

10,080 ULTRASONIC ATTENUATION IN SUPERCONDUCTORS by T. Tsuneto (U. Illinois); *Phys. Rev.*, Vol. 121, pp. 402-415, Jan. 15, 1961

A general treatment of ultrasonic attenuation of both longitudinal and transverse waves in superconductors, valid for an arbitrary mean free path, is given on the basis of the Bardeen-Cooper-Schrieffer theory. The interaction between the ultrasonic waves and electrons is assumed to be given by a self-consistent electromagnetic field. Instead of the customary theory of the attenuation based on the Boltzmann equation, a different formation is developed using the density-matrix formalism. The ratio of the attenuations in superconducting and normal metals for the longitudinal wave turns out to be approximately independent of the mean free path. The attenuation of the shear wave due to electromagnetic interaction is shown to be very small in the superconducting state.

10,081 ISOTOPE EFFECT IN SUPERCONDUCTING LEAD by R. W. Shaw, D. E. Mapother, and D. C. Hopkins (U. Illinois); *Phys. Rev.*, Vol. 121, pp. 86-90, Jan. 1, 1961

Measurements of the difference in critical fields of superconducting Pb specimens with various isotopic masses are reported. The results near  $T_c$  are consistent with the relation  $T_c = \text{const} \times M^p$ , where M is the average isotopic mass, and yield a value  $p = -0.478 \pm 0.014$ . The measurements at lower temperatures confirm the similarity principle to within approximately 0.1 per cent and indicate that  $\gamma$ , the coefficient in the normal electronic specific heat, is independent of isotopic mass to a similar accuracy.

10,082 EFFECT OF RESIDUAL GASES ON SUPERCONDUCTING CHARACTERISTICS OF TIN FILMS by H. L. Caswell (IBM); *J. Appl. Phys.*, Vol. 32, pp. 105-114, Jan. 1961

A special oil-free, ultra-high vacuum system which has been used to deposit tin films at pressures less than  $10^{-9}$  mm Hg onto room temperature substrates is described. These films were found to possess extremely sharp and reproducible magnetic field transitions as compared to films deposited by more conventional techniques. This resulted from breakup of the penumbra of a film deposited through a mask into electrically discontinuous islands leaving a film of uniform thickness. Specific residual gases were found to decrease the surface mobility of the tin atoms which contributed to continuous film edges and higher critical fields. For example, the critical field extrapolated to 0°K increased from 370 oe for a pure film to 490, 590, and 820 oe as the ratio of oxygen molecules to tin atoms striking the substrate increased from 0 to 3, 6, and 9 per cent respectively. For more highly doped films the bulk characteristics were also altered, indicating the presence of oxygen in the film material. Water vapor and carbon dioxide were found also to alter the edge structure, whereas  $\text{N}_2$ ,  $\text{H}_2$ ,  $\text{CH}_4$ ,  $\text{C}_3\text{H}_8$ ,

$\text{C}_5\text{H}_{12}$ , A, and CO did not. By analyzing the critical field and residual resistance data of the various films, the vacuum requirements necessary for obtaining high purity films with sharp magnetic transitions occurring at predictable field values were ascertained. An ultra-high vacuum system is not required if the partial pressure of critical gases is maintained below specified values.

10,083 FREQUENCY-DEPENDENT HALL EFFECT IN NORMAL AND SUPERCONDUCTING METALS by P. B. Miller (U. Illinois); *Phys. Rev.*, Vol. 121, pp. 435-450, Jan. 15, 1961

The Hall current flow occurring in a normal and a superconducting metal when both a static magnetic field ( $H_0$ ) and an electromagnetic wave are applied on the metal is calculated. The entire frequency range of the electromagnetic wave is discussed although the emphasis is on the microwave range. The nonlocal, transverse Hall current in a normal metal is calculated by solving the Boltzmann equation. It is shown that the microwave Kerr rotation in a circular cylindrical cavity provides a good test for the nonlocal Hall current in a normal metal. The relation between a longitudinal and a transverse Hall current in a superconductor is briefly discussed. A detailed theory of the transverse Hall current in a superconductor based on the Bardeen-Cooper-Schrieffer model and including the effect of collective excitations is presented. The field  $H_0$  is assumed constant in space and a general result for the Hall current in Q space is derived. When the electric field is constant in space ( $Q \rightarrow 0$ ), it is shown that the Hall current is proportional to the microscopic analog of the fraction of normal electrons of a two-fluid model.

## OTHER ELECTRICAL PROPERTIES

Avalanche Breakdown in PN Junctions - See 10,163

Photo-Hall Effect - See 10,070

Hall Coefficient of GaSb - See 10,073

Hall Coefficient of Te - See 10,094

Hall Effect in  $\text{Ag}_2\text{Te}$  - See 10,061

10,084 DETERMINATION OF THE ACTIVATION ENERGY OF THE WORK-FUNCTION STABILIZATION PROCESS OF THE GOLD-BARIUM SYSTEM by E. D. Pavlovskaya, I. L. Sokol'skaya, and Yu. G. Shishkin (Leningrad State U.); *Soviet Phys.-Solid State*, Vol. 2, pp. 1671-1672, Feb. 1961

The activation energy, E, of a gold-barium intermetallic compound formed when layers of those elements are deposited on a tungsten strip and subsequently heated is evaluated. Formation of the compound stabilizes the work-function at 3.3 ev. In the determination of E, the temperature of a tungsten strip as a function of the current heating it was measured accurately from 20 to 1000°C. After gold and barium layers were deposited in equal thickness on the tungsten, the time required to achieve the stable work-function value was determined between 300 and 450°C, and thence plotted as a function of temperature. The slope of this curve is E; its value is  $0.8 \pm 0.1$  ev.



## OTHER ELECTRICAL PROPERTIES (Cont'd)

10,085 THERMIONIC AND PHOTOELECTRIC EMISSION FROM MAGNESIUM OXIDE by J. R. Stevenson and E. B. Mansley (U. Missouri); J. Appl. Phys., Vol. 32, pp. 166-172, Feb. 1961

Measurements of the thermionic emission as a function of temperature and the photoelectric yield as a function of the photon energy in the range from 2.5 eV to 11.5 eV which have been made on magnesium oxide in the form of thin films, powders, and single crystals are reported. The thermionic emission measurements indicate that the position of the Fermi energy in most samples of MgO is controlled primarily by the electrons in a donor level located approximately 3.4 eV below the vacuum level. Measurements of the enhancement of the photoelectric yield in the impurity sensitive region gives evidence for impurity levels slightly greater than 2.4 eV and 5 eV below the bottom of the conduction band. A sharp rise in yield at 7.5 eV in active samples coincides with the optical absorption edge associated with exciton formation. Heating the samples in oxygen greatly reduces the rise at 7.5 eV but has little effect on the yield at energies greater than 10 eV. From this it is concluded that the energy difference from the top of the filled band to the vacuum level is less than 10 eV.

Photoelectric Properties of PN Junctions in SiC - See 10,137

Photo-Electron Emission from Irradiated Iron Oxide Catalysts - See 10,138

10,086 CONTRIBUTION OF BACKSCATTERED ELECTRONS TO SECONDARY ELECTRON FORMATION by H. Kanter (Westinghouse Res. Labs.); Phys. Rev., Vol. 121, pp. 681-684, Feb. 1, 1961

It is shown experimentally that backscattered electrons emitted from solids under electron bombardment contribute significantly to the observed secondary yield, even for the case of low backscattering coefficients. Thus, it was found that in Al with a backscattering coefficient of only 0.14, about 40 per cent of all secondaries are produced by backscattered electrons for initial energies from several keV to several tens of keV. The large contribution of backscattered electrons to secondary formation even for materials of low atomic number agrees approximately with what one would expect from the larger rate of energy loss and the greater path lengths of the backscattered electrons in the secondary electron escape region compared to that of the incoming primaries.

10,087 ENERGY DISSIPATION AND SECONDARY ELECTRON EMISSION IN SOLIDS by H. Kanter (Westinghouse Res. Labs.); Phys. Rev., Vol. 121, pp. 677-681, Feb. 1, 1961

Experimental evidence for the proportionality between secondary electron yield and the energy dissipated by electrons near the surface of a solid is presented. Using measurements of the energy carried away by electrons transmitted and reflected from thin foils of aluminum and carbon, the energy dissipated in an incremental layer at the exit surface was obtained. Simultaneous measurements of the secondary electron yield showed a close proportionality between the number of secondaries produced and the energy dissipation density near the surface independent of the incident electron energy between 1 and 10 keV. By subtracting the contribution of the backscattered electrons to the yield at the front surface of a thick aluminum target, the yield of secondaries was found to be proportional to the rate

of energy loss calculated from the Bohr-Bethe theory over the energy range investigated.

10,088 EMISSION PROPERTIES OF SILICON TREATED IN CESIUM VAPORS by V. G. Bol'shov, L. V. Vasil'eva and G. N. Pautova (Physicotech. Inst.); Soviet Phys.-Solid State, Vol. 2, pp. 1783-1785, Feb. 1961

The thermionic, photoelectric, and secondary-electron emission of Si single crystals after treatment in Cs vapor, as well as of Si films condensed on molybdenum or ultraviolet-transmitting glass and similarly treated, are discussed. The variation of Si work-function with temperature is shown in a family of curves for various Cs temperatures. An increase in the Cs temperature decreases the work-function of Si at all its operating temperatures. The spectral distributions of three Cs vapor-treated samples are shown. The secondary-electron emission coefficient of Si films increases four- to fivefold following treatment of the films with Cs vapor.

Microplasmas in PN Junctions - See 10,163

10,089 THEORY OF TUNNELING by E. O. Kane (Hughes Res. Labs.); J. Appl. Phys., Vol. 32, pp. 83-91, Jan. 1961

The theory of "direct" and "phonon-assisted" tunneling is reviewed. Theoretical I-V characteristics are calculated using the constant field model. Generalizations to nonconstant field and more complicated band structure models are discussed briefly.

10,090 TUNNELING THROUGH THIN INSULATING LAYERS by J. C. Fisher and I. Giaever (GE Res. Labs.); J. Appl. Phys., Vol. 32, pp. 172-177, Feb. 1961

Measurements of the resistance of thin aluminum-oxide films as a function of the voltage across the film and of the film thickness as calculated from its capacitance are reported. All films showed ohmic behavior at low voltages, and exponential rise of current at higher voltages, in qualitative agreement with R. Holm's theoretical calculations for tunneling through thin vacuum layers. However, the resistance was several orders of magnitude lower than either the bulk value for  $Al_2O_3$  or the calculated value for tunneling through vacuum. By making use of an effective mass in the oxide equal to about 1/9 of the electron mass, the calculated values for tunneling can be brought into line with the experimental results.

10,091 CERTAIN PROPERTIES OF THALLIUM SELENIDE MONOCRYSTALS by G. A. Akhundov, G. B. Abdullaev, and G. D. Guseinov (Phys. Inst., Baku); Soviet Phys.-Solid State, Vol. 2, pp. 1378-1380, Jan. 1961

The preparation, electrical conductivity, and Hall effect of monocrystalline TlSe are discussed. The specimens investigated ranged in resistivity from one to 49 ohm-cm, at room temperature. As the temperature was increased, the conductivity decreased, passed through a minimum, then increased. The specimen of greatest resistivity (49 ohm-cm) retained its semiconductor properties throughout the temperature range investigated. The temperature dependence of conductivity is discussed; at all temperatures the conductivity was p-type.

10,092 SEMICONDUCTING PROPERTIES OF THE  $AgFeTe_2$  PHASE by E. L. Shtrum (Inst. Semicon., Leningrad); Soviet Phys.-Solid State, Vol. 2, pp. 1352-1355, Jan. 1961

The semiconductor properties and phase changes of  $AgFeTe_2$ , as



## OTHER ELECTRICAL PROPERTIES (Cont'd)

well as the semiconductor properties and structure of compositions which differ slightly from stoichiometric  $\text{AgFeTe}_2$ , are evaluated.  $\text{AgFeTe}_2$  undergoes solid-phase transformation at  $150^\circ$  and  $520^\circ\text{C}$ . Microphotographs of specimens quenched from various temperatures are presented. Within a wide compositional range, there is little variation in electrical conductivity and thermal emf, and the compound retains its semiconductor properties. The probable reason for this consistency is discussed in detail.

Electrical Properties of Li or Na Doped MnTe - See 10,020

## MAGNETIC PROPERTIES

10,093 MEASUREMENT OF MAGNETIC SUSCEPTIBILITY IN VERY HIGH PULSED FIELDS by R. Stevenson (McGill U.); Rev. Sci. Instr., Vol. 32, pp. 28-31, Jan. 1961

A technique for making Gouy type measurements of magnetic susceptibility in high transient magnetic fields is described. The magnetic force on the sample travels as a stress wave through the apparatus assembly and excites a voltage on two piezoelectric crystals which are the active elements of the transducer. The apparatus has a small risetime and high response. Typical experimental difficulties are described.

10,094 MAGNETIC SUSCEPTIBILITY AND GALVANOMAGNETIC EFFECTS IN PURE AND P-TYPE TELLURIUM by G. Fischer (Nat'l. Res. Council, Canada) and F. T. Hedgcock (U. Ottawa); J. Phys. Chem. Solids, Vol. 17, pp. 246-253, Jan. 1961

Measurements of the magnetic susceptibility, resistivity and Hall constant of samples of tellurium with various charge carrier densities between  $4.2^\circ\text{K}$  and  $500^\circ\text{K}$  are reported. Pure tellurium shows a temperature independent susceptibility between room temperature and the temperature of liquid helium. All heavily doped samples show a temperature dependent diamagnetism which is thought to arise from the free charge carriers. The magnetic susceptibility and galvanomagnetic effects are interpreted with a simple two band model. Hole effective masses, based on the two band interpretation of the susceptibility measurements, are found to range from 0.14m to 0.24m. An impurity scattering effective mass of 0.2m is found for the holes in the most degenerate sample. Magnetic evidence for the trapping of charge carriers can be seen in the liquid helium region and an estimate of 0.004eV is obtained for the activation energy of hole formation. All samples show an unexplainable temperature dependent paramagnetic contribution to the susceptibility above room temperature.

10,095 THRESHOLD CONCENTRATION FOR THE EXISTENCE OF FERROMAGNETISM IN DILUTE ALLOYS by M. Cooper-smith and R. Brout (Cornell U.); J. Phys. Chem. Solids, Vol. 17, pp. 254-258, Jan. 1961

Previous calculations by Brout for a magnetically dilute system give a value of  $x_0 Z = 1$  for the suppression of ferromagnetism, where  $x_0$  is the concentration below which ferromagnetism does not exist and  $Z$  is the number of nearest neighbors. Only nearest neighbor exchange forces are assumed to exist. This value was obtained using the first term in the cluster expansion of

$1/N < \log < Z >_R > C$ . In this paper, a more exact expression for  $x_0 Z$  is obtained by evaluating the higher order terms in the cluster expansion. It is found that  $x_0 Z \simeq 4/3$  for simple, body-centered and face-centered cubic lattices.

Heat Capacity of Ferromagnetic Superconductors - See 10,141

10,096 MAGNETIC RELAXATION SPECTRUM OF FERRITES  $\text{Mn}_x\text{Fe}_{3-x}\text{O}_4 + \gamma$  by S. Krupicka and F. Vilim (Inst. Tech. Phys., Prague); Czech. J. Phys., Vol. 11B, No. 1, pp. 10-17, 1961

A study of the initial permeability disaccommodation in ferrites  $\text{Mn}_x\text{Fe}_{3-x}\text{O}_4 + \gamma$ ,  $0.5 \leq x \leq 1$ , in a temperature range around  $-200^\circ$  to  $+180^\circ\text{C}$  is reported. Four separate bands were found in the relaxation spectrum of these ferrites.

10,097 THEORY OF THE MAGNETIC ANISOTROPY IN  $\text{KMnF}_3$  by J. J. Pearson (U. Pittsburgh); Phys. Rev., Vol. 121, pp. 695-702, Feb. 1, 1961

A theoretical calculation of the magnetic anisotropy in the cubic perovskite structure of  $\text{KMnF}_3$  at room temperature and in its distorted structures at lower temperatures is given. These distortions are of two types: first, a small tetragonal distortion of the entire crystal; and then, below the antiferromagnetic Néel point, a distortion of the octahedron of fluorine atoms surrounding each manganese. The cubic anisotropy is obtained from a general spin-wave calculation of the zero-point dipole-dipole energy in a cubic antiferromagnet. The result is found to be the same as that for the ferromagnetic case. The anisotropy from the tetragonal distortion is obtained from the change in the classical Lorentz factors. In calculating the effect of the fluorine distortion, a generalization of Kondo's method for obtaining the anisotropic effective spin Hamiltonian produced by overlap and electron transfer between an  $\text{Mn}^{++}$  ion and its non-magnetic neighbors is introduced. In its present form the method permits the ready calculation of this anisotropy for any symmetry and number of neighbors. Comparison with the microwave resonance and torque measurements of Portis, Teaney, and Heeger reveals the last effect to be the most important and confirms the form of the spin Hamiltonian and its approximate magnitude.

10,098 GYROMAGNETIC RATIOS OF MANGANESE ALLOYS by G. G. Scott (GM Res. Labs.); Phys. Rev., Vol. 121, p. 104, Jan. 1, 1961

Measurements of the gyromagnetic ratios of two different ferromagnetic alloys of manganese by Einstein-deHaas experiments are reported. The Heusler alloy  $\text{Cu}_2\text{MnAl}$  gave a  $g'$  value of  $1.993 \pm 0.002$ . The alloy  $\text{MnSb}$  gave a  $g'$  value of  $1.978 \pm 0.002$ .

10,099 MAGNETIC PROPERTIES OF  $\text{KMnF}_3$ . I. CRYSTALLOGRAPHIC STUDIES by O. Beckman (U. California) and K. Knox (Bell Labs.); Phys. Rev., Vol. 121, pp. 376-380, Jan. 15, 1961

Measurements of the lattice parameters for  $\text{KMnF}_3$  by means of an x-ray rotation camera designed for temperatures down to  $15^\circ\text{K}$  are reported. The cubic room temperature perovskite structure transforms at  $184^\circ\text{K}$  to an orthorhombic phase with  $D_{2h}^{16}$ -Pbnm as the most probable space group with a unit cell containing 4 formula units; it has a tetragonal pseudocell with  $c/a > 1$  in which the fluorine octahedra about the manganese remain essentially regular but tilt relative to the crystal axes. At  $84^\circ\text{K}$ , just below the Néel temperature of  $88^\circ\text{K}$ , the pure



antiferromagnetic also has a tetragonal pseudocell, but with  $a < 1$  and the still essentially regular octahedra rotated as well as twisted. Below a second magnetic transition at  $81.5^\circ\text{K}$ , the  $65^\circ\text{K}$  structure shows in addition a significant distortion of the regularity of the octahedra.

10,100 ROLE OF DOUBLE EXCHANGE IN THE MAGNETIC STRUCTURE OF  $\text{Li}_x\text{Mn}_{1-x}\text{Se}$  by R. R. Heikes (Westinghouse Res. Labs.), T. R. McGuire and R. J. Happel, Jr. (U.S. Naval Ord. Lab.); Phys. Rev., Vol. 121, pp. 703-707, Feb. 1, 1961

The details of the magnetic behavior of the  $\text{Li}_x\text{Mn}_{1-x}\text{Se}$  system are attributed to the double-exchange interaction. At low temperatures, the hole which is introduced by the  $\text{Li}^+$  is loosely bound to the  $\text{Li}^+$  itself. In the region of the Li ion, double exchange causes local distortions of the spin system which are referred to as clusters. As the Li concentration is increased ( $x = 0.07$ ), the clusters overlap sufficiently so that a magnetic field will induce an appreciable magnetic moment ( $0.5\mu_B$ ). At temperatures below  $45^\circ\text{K}$  a canted spin ordering is suggested; the magnetic model for the  $x = 0.07$  composition. Finally, for  $x = 0.10$  it is found that spontaneous magnetization develops below  $110^\circ\text{K}$ . As the temperature is lowered through  $70^\circ\text{K}$  the spontaneous moment disappears and antiferromagnetism is found. This is not inconsistent with the data for  $x = 0.10$  that this antiferromagnetic state is a canted-spin system with very small canting angle and therefore small magnetic moment. The theory of de Gennes is used in a discussion of the magnetic model.

10,101 MAGNETIC STRUCTURE TRANSITIONS IN  $\text{Li}_x\text{Mn}_{1-x}\text{Se}$  by S. J. Pickart (U.S. Naval Ord. Lab.), R. Nathans (Pennsylvania State U.) and G. Shirane (Westinghouse Res. Lab.); Phys. Rev., Vol. 121, pp. 707-714, Feb. 1, 1961

A study of the magnetic structures occurring in lithium-substituted manganese selenide ( $\text{Li}_x\text{Mn}_{1-x}\text{Se}$ ) by low-temperature powder neutron diffraction measurements is reported. The composition with  $x = 0.05$  retains the fcc ordering of the second kind found in  $\text{MnSe}$ , the transition temperature being lowered to  $83^\circ\text{K}$ . For  $x = 0.07$  the same type of ordering sets in at  $73^\circ\text{K}$ , but the spin direction changes abruptly as the temperature is lowered through  $45^\circ\text{K}$ ; furthermore, the superlattice intensities decrease when an external magnetic field is applied along the scattering vector. At  $x = 0.10$ , the spontaneous moment observed at  $77^\circ\text{K}$  by magnetization measurements is shown to be ferromagnetic, again by means of an external field, and a transition is found at  $71^\circ\text{K}$  from ferromagnetism to antiferromagnetism with the third kind of ordering. The results are discussed with relation to models containing canted spins and multiple antiferromagnetic axes.

10,102 NEUTRON DIFFRACTION INVESTIGATION OF MAGNETIC ORDERING IN THE TRIFLUORIDES OF 4d-TRANSITION ELEMENTS by M. K. Wilkinson, E. O. Wollan, H. R. Child, and J. W. Cable (Oak Ridge Natl. Lab.); Phys. Rev., Vol. 121, pp. 74-77, Jan. 1, 1961

It is reported that  $\text{MoF}_3$  becomes antiferromagnetic below  $185^\circ\text{K}$  with a spin-only magnetic moment corresponding to  $S = 3/2$  and a magnetic structure which can be correlated with coupling rules applicable to the iron-group trifluorides. These results, together with the absence of observable magnetic neutron scattering from  $\text{PdF}_3$  and  $\text{RuF}_3$ , suggest that Hund's rule does not apply to ions in the 4d-transition series.

10,103 NUCLEAR MAGNETIC RESONANCE AND MAGNETIC ORDERING IN  $\text{NiF}_2$  by R. G. Shulman (Bell Labs. and U. Copenhagen); Phys. Rev., Vol. 121, pp. 125-143, Jan. 1, 1961

Measurements of the nuclear magnetic resonance of the  $\text{F}^{19}$  nucleus in single crystals of  $\text{NiF}_2$  at temperatures between  $4.2^\circ\text{K}$  and  $298^\circ\text{K}$  are reported. In the paramagnetic state at  $298^\circ\text{K}$ , for arbitrary directions of  $H_0$  two resonances were observed, while for  $H_0$  in a (100) plane only one resonance was observed as expected from the crystal symmetry. The shift of the resonances from the normal resonance field  $\omega/\gamma_N$  allows one to calculate three independent parameters of the hyperfine interaction between the  $\text{F}^{19}$  nuclei and the magnetic electrons. In conjunction with measurements made in the antiferromagnetic state, the individual components of the hyperfine interaction and from them the fractions of unpaired spin in the corresponding fluoride ion  $s$  and  $p_\sigma$  orbitals have been determined. At temperatures just above the antiferromagnetic transition  $T_N = 73.2^\circ\text{K}$ , the resonance shifts with  $H_0$  in the (001) plane change rapidly with temperature. Between  $75.7^\circ\text{K}$  and  $T_N$  the susceptibility of one sublattice becomes negative while the other remains positive. This has been correlated with the sublattice susceptibility derived by Moriya from the spin Hamiltonian  $\mathcal{H} = g\beta H + DS_z^2 + E(S_x^2 - S_y^2)$ . By fitting the theoretical susceptibility the sign of  $E$  in this Hamiltonian has been determined.

10,104 THEORY OF FERRO- AND ANTIFERROMAGNETIC RESONANCE ABSORPTION by T. Oguchi and A. Honma (Tokyo U.); J. Phys. Soc. Japan, Vol. 16, pp. 79-94, Jan. 1961

The resonance conditions in ferro- and antiferromagnetic resonance absorptions are obtained by the spin-wave theory. According to the usual free spin-wave theory, the resonance frequency is independent of temperature and has only the value at  $0^\circ\text{K}$ . The spin-wave interactions give the correct temperature dependence for the resonance frequency. As a result of including these interactions, the ferromagnetic resonance condition taking account of the anisotropy energy agrees with Kittel's formula. For the cases of ferromagnetic resonance including the demagnetizing effect and antiferromagnetic resonance the resonance conditions obtained at high temperatures agree with the formulae of Kittel and Nagamiya, Keffer-Kittel respectively, but at low temperatures these conditions show a temperature dependence which differs from their formulae. This new theoretical result is not in agreement with the experimental data in  $\text{MnF}_2$  by Jaccarino-Shulman and Johnson-Nethercot.

10,105 DETERMINATION OF PARAMETERS IN EQUATION FOR FERROMAGNETIC RESONANCE OF FERRITES by Z. Frajt (Inst. Phys., Prague); Czech. J. Phys., Vol. 11B, No. 1, pp. 1-9, 1961

A new method for determining the parameters in the equation for ferromagnetic resonance — the internal effective field, the spectroscopic splitting factor, and the saturation magnetization in polycrystalline magnetically isotropic ferrites — is described. Relations are derived for calculating these parameters by means of the values of the resonance external static fields which are obtained by measurements on samples having various geometrical shapes and various arrangements of static and microwave magnetic fields. The advantages and disadvantages of the method are discussed.

10,106 LONGITUDINAL FERRIMAGNETIC RESONANCE by R. K. Wangsness (U.S. Naval Ord. Lab.); Phys. Rev., Vol.



## MAGNETIC PROPERTIES (Cont'd)

121, p. 472, Jan. 15, 1961

Susceptibility components are calculated for a triangular ferromagnetic system when the oscillating field is parallel to both the constant field and the net magnetization. Two new effects which are analogous to one discussed previously are found. They consist in the production of oscillating magnetization components of the same frequency as the external field which are parallel and perpendicular to the net magnetization.

10,107 THE RELATION OF TRANSITION PARAMETERS FOR LINEAR PROCESSES TO MEASURABLE PARAMETERS IN FERRIMAGNETIC RESONANCE by P. E. Seiden (U. Grenoble); J. Phys. Chem. Solids, Vol. 17, pp. 259-266, Jan. 1961

Expressions for linear processes that relate the fundamental transition parameters for relaxation in ferrimagnetic resonance to measurable parameters such as linewidths and relaxation times are derived. These calculations include the effect of the reaction of spin waves back onto the uniform precession. Previous calculations by others have neglected this effect; the consequences of its neglect are discussed.

10,108 NOTE ON FERROMAGNETIC RELAXATION EQUATIONS by H. Suhl and R. C. Fletcher (Bell Labs.); J. Appl. Phys., Vol. 32, pp. 281-282, Feb. 1961

An amplitude formulation is employed for determining the motion of the electron spins in a ferromagnetic insulator in the presence of scattering from inhomogeneities. This formulation justifies the omission of an explicit back reaction term in previous "energy" and "number of quanta" formulations in the usual case where a large number of spin waves are excited by the scattering centers. The excited spin waves add up in such an incoherent fashion that they do not react back on the principal mode.

10,109 THEORY OF THE MAGNETIC SUSCEPTIBILITY OF HOLES IN GERMANIUM by J. M. Luttinger and P. J. Stiles (U. Pennsylvania); J. Phys. Chem. Solids, Vol. 17, pp. 284-291, Jan. 1961

A general method for calculating the field independent magnetic susceptibility of free holes in degenerate and simple bands is described. This method is applied to the valence band of Ge. Results for both Maxwell-Boltzmann and Fermi-Dirac statistics are given and the possibility of comparison with experiments is discussed.

10,110 MAGNETIC STUDIES ON SINGLE-CRYSTAL CHROME POTASSIUM ALUM BELOW 1° KELVIN by A. C. Thorsen (Rice U.); Phys. Rev., Vol. 121, pp. 66-71, Jan. 1, 1961

Measurements of the magnetic susceptibility of a spherically shaped single crystal of chrome potassium alum as a function of entropy and applied external field along the [100], [110], and [111] directions in the crystal at temperatures below 0.1°K are reported. Zero-field measurements of the static susceptibility were made with a moving coil apparatus and longitudinal field measurements were made using the conventional ballistic bridge method. A ballistic galvanometer with period 4.6 seconds was used in both circuits. Drop coil measurements indicate no long-time effects in the magnetization and show no appreciable difference from the susceptibility measured by the ballistic method. The isentropic susceptibility measured in fields up to 300 gauss indicates definite anisotropy below the Néel point in fields from 50 to 300 gauss.

10,111 DEFECTS IN IRRADIATED SILICON. I. ELECTRON SPIN RESONANCE OF THE Si-A CENTER by G. D. Watkins and J. W. Corbett (GE Res. Labs.); Phys. Rev., Vol. 121, pp. 1001-1014, Feb. 15, 1961

It is concluded that the Si-A center, a major radiation-damage defect produced in "pulled" silicon by a room temperature irradiation, is a lattice vacancy with an oxygen atom impurity bridging two of the four broken bonds associated with the vacancy. Spin resonance and electrical activity arise from an electron trapped in the other two bonds. A molecular orbital treatment of the trapped electron wave-function satisfactorily accounts for the observed g tensor, as well as the hyperfine interaction observed with neighboring 4.7% abundant Si<sup>29</sup> nuclei. The changes in the spectrum of a sample subjected to uniaxial stress are also described. Under stress, the amplitudes of the individual resonance components (which correspond to different orientations of the defect in the crystal) are observed to change. This results from (1) electronic redistribution of the trapped electrons among the defects, and (2) thermally activated reorientation of the defects themselves under the applied stress. These two effects are separated and a quantitative study of their magnitudes and signs, as well as their rates, is given. The results confirm many of the important microscopic features of the model.

10,112 PARAMAGNETIC RESONANCE STUDY OF IRRADIATED SINGLE CRYSTALS OF CALCIUM TUNGSTATE by H. Zeldes and R. Livingston (Oak Ridge Natl. Lab.); J. Chem. Phys., Vol. 34, pp. 247-252, Jan. 1961

Gamma irradiation of calcium tungstate at 77°K produces two paramagnetic species in high yield. Measurements of yields and of rates of disappearance upon warming which indicate that the two species are formed and disappear upon warming in one to one correspondence are reported. The principal axis directions and g tensors indicate that one species contains a surplus electron while the other is electron-deficient (hole). Hyperfine effects of W<sup>183</sup> have been observed. The electron-deficient species contains two tungsten atoms with small isotropic hyperfine interactions. Its unpaired electron must be highly localized in orbitals of atoms other than tungsten. The electron-surplus species contains one tungsten atom with an anisotropic hyperfine interaction. This center could be WO<sub>4</sub><sup>3-</sup>, but from the lack of symmetry of the measured g values it must be formed near a lattice defect. Experiments with heat-treated crystals indicate lattice defects to be important in the radiation effect.

10,113 NUCLEAR MAGNETIC RESONANCE IN SUPERCONDUCTING TIN by G. M. Androes and W. D. Knight (U. California); Phys. Rev., Vol. 121, pp. 779-787, Feb. 1, 1961

Measurements of the nuclear magnetic resonance (NMR) in small particles (~100 Å diam) of β tin between 1.5° and 4.2°K, and in magnetic fields between 1.2 and 8.8 kilogauss are reported. The critical temperature and critical field are 3.71°K and 25 kilogauss, respectively. The effective penetration depth for the superconducting particles is estimated to be 1500 Å. The resonance linewidth is 0.34% of the magnetic field, and it is independent of temperature. With respect to a tin, the NMR shift for β tin is 0.77% in the normal state; it approaches 0.59% in the superconductor as T→0. (The largest known chemical shift is only 0.17%). The variation with magnetic field is less than 0.03%. One may conclude that the electronic spin susceptibility in the superconducting particles at absolute zero is approximately three quarters of the normal value. The result for 1000 Å particles, though less accurate, is substantially the same.



## MAGNETIC PROPERTIES (Cont'd)

10,114 PARAMAGNETIC RESONANCE OF  $\text{Fe}^{3+}$  IN OCTAHEDRAL AND TETRAHEDRAL SITES IN YTTRIUM GALLIUM GARNET (YGG) AND ANISOTROPY OF YTTRIUM IRON GARNET (YIG) by S. Geschwind (Bell Labs.); Phys. Rev., Vol. 121, pp. 363-374, Jan. 15, 1961

Measurements of the electron paramagnetic resonance spectrum of a small  $\text{Fe}^{3+}$  impurity which enters substitutionally for the gallium in single crystals of yttrium gallium garnet (chemical formula  $\text{Y}_3\text{Ga}_5\text{O}_{12}$ ) at 24 kMc/sec at  $295^\circ\text{K}$  and  $1.6^\circ\text{K}$  are reported.  $\text{Fe}^{3+}$  is studied for the first time in tetrahedral coordination. The results for the crystal field parameters that appear in the usual spin Hamiltonian for  $\text{Fe}^{3+}$  for the octahedral (a) and tetrahedral (d) sites are:  $a_a = +0.0185\text{cm}^{-1}$ ,  $D_a = +0.1294\text{cm}^{-1}$ ,  $F_a = +0.0026\text{cm}^{-1}$ ,  $a_d = +0.0062\text{cm}^{-1}$ ,  $D_d = +0.0880\text{cm}^{-1}$ ,  $F_d = -0.0037\text{cm}^{-1}$ . The finding of a positive  $F$  in both types of sites where the cubic crystalline potential,  $V$ , has opposite signs indicates that in the mechanism responsible for this splitting terms proportional to even powers of  $V$  are dominant. Using the experimentally determined crystal field parameters of  $\text{Fe}^{3+}$  in YGG, the low-temperature anisotropy energy per unit cell in the isostructural ferrimagnet, YIG, is predicted as  $K_1 = -0.370\text{cm}^{-1}$ . This is 50 per cent larger than the experimental value  $K_1 = -0.250\text{cm}^{-1}$  and several sources for the origin of this discrepancy are suggested.

## OPTICAL PROPERTIES

10,115 SLIT-WIDTH ERROR IN THE MEASUREMENT OF ABSORPTION CONSTANTS by A. Lempicki, H. Samelson and A. Brown (Genl. Tel. Electronics Labs.); J. Opt. Soc. Am., Vol. 51, pp. 35-40, Jan. 1961

The nature of the distribution of energy emergent from the slit of an optical monochromator is discussed. It is found to be nearly Gaussian. The information is used to find the true transmission by the method of Hardy and Young and two specific examples are given as an illustration.

10,116 RADIATION INDUCED OPTICAL ABSORPTIONS IN CRYSTALLINE QUARTZ AND FUSED SILICA by K. Kubo (Tokai Res. Est.); J. Phys. Soc. Japan, Vol. 16, pp. 108-113, Jan. 1961

Measurements of the optical absorption of  $\gamma$ - and fast neutron-irradiated crystalline quartz and fused silica from  $186\text{ m}\mu$  to  $22.6\text{ m}\mu$  are reported. Dichroism of the A-band was confirmed. The phenomenon of radiation bleaching of the  $B_1$ -band and a remarkable movement of the C-band were found. The irradiation and optical bleaching experiments showed that only the C-band is essentially due to radiation, and this was considered to be caused by an absorption center similar to the F-center which changes to an  $F'$ - or colloidal-center with subsequent irradiation.

10,117 ABSORPTION SPECTRA OF  $\text{F}_2^-$ ,  $\text{Cl}_2^-$ ,  $\text{Br}_2^-$ , and  $\text{I}_2^-$  IN THE ALKALI HALIDES by C. J. Delbecq, W. Hayes and P. H. Yuster (Argonne Natl. Lab.); Phys. Rev., Vol. 121, pp. 1043-1050, Feb. 15, 1961

After x-ray irradiation at liquid nitrogen temperature, holes are trapped by forming  $\text{F}_2^-$  molecule ions in LiF;  $\text{Br}_2^-$  molecule ions in KBr containing one of the impurities  $\text{Ag}^+$ ,  $\text{Tl}^+$ ,  $\text{Pb}^{++}$ , or  $\text{NO}_2^-$ ; and  $\text{I}_2^-$  molecule ions in KI containing one of the

impurities listed above. An investigation of the optical and paramagnetic resonance spectra of crystals containing  $\text{F}_2^-$ ,  $\text{Br}_2^-$ , and  $\text{I}_2^-$  centers leads to an identification of the optical transitions of these centers. The polarizations and relative intensities of the optical absorptions in the  $\text{X}_2^-$  molecule ion series are discussed with reference to the energy level scheme to be expected for such a species.

10,118 SPECTROPHOTOMETRIC STUDY OF THE YELLOW SERIES OF  $\text{Cu}_2\text{O}$  AT LOW TEMPERATURES by S. Nikitine, J. B. Grun, and M. Sieskind (U. Strasbourg); J. Phys. Chem. Solids, Vol. 17, pp. 292-300, Jan. 1961

A study of the "yellow" series of absorption lines in  $\text{Cu}_2\text{O}$  crystals by spectrophotometric methods at different temperatures down to liquid helium is reported. The experimental values of the oscillator strength of the absorption lines have been determined. The oscillator strength of the first lines ( $n = 2$ ) is  $f_2 = 2.8 \times 10^{-6}$ ; the relative oscillator strength  $f_0(n) = f_n/f_2$  has been calculated from experimental data for different lines.  $f_0(n)$  is however determined with a sufficient accuracy for the very first lines of the series only. Both the value of  $f_2$  and the relative oscillator strength in the series are in good agreement with Elliott's theory of forbidden exciton transitions. These arguments added to others already known give a very solid basis to the interpretation of the "yellow" series of  $\text{Cu}_2\text{O}$  as a forbidden exciton spectrum. It has been shown that the maximum of the coefficient of absorption in a line  $K_{\text{max}}$  decreases with the quantum number  $n$  according to a law  $K_{\text{max}} \propto 1/n^2$  for  $n \geq 3$ . The lines are of a very asymmetric form. A parameter is introduced to characterize this property. The variation of this parameter with  $n$  is investigated. The form of the first line ( $n = 2$ ) differs very much from the form of the other lines of the series. According to the data, the life time of excitons increases with  $n$ ; this result is not inconsistent with Toyozawa's theory.

10,119 PROPERTIES OF LITHIUM HYDRIDE-II OPTICAL ABSORPTION BY COLOR CENTERS by F. E. Pretzel (U. California); J. Phys. Chem. Solids, Vol. 17, pp. 232-245, Jan. 1961

The optical properties of color centers involving trapped electrons in LiH show that properties of the crystalline media other than the lattice parameter are important in relation to the energy of the optical absorption bands. The F band in LiH is found at 2.4 eV instead of at 4.8 eV, as predicted by the Ivey formula for F bands in the alkali halides. Other properties of the F band in LiH are consistent with expectations from the F-center model and with the high vibrational frequency and high cation-vacancy mobility in LiH crystals. The M band, Li-colloid band and other bands in LiH are also shifted to lower energy; therefore, the sequence of bands in LiH is comparable to the familiar sequence found in KCl. The principal V band in LiH is at 3.5 eV. The properties of the center responsible for the V band are consistent with those of an  $\text{H}_2$  molecule trapped at an anion site. This is the same as one proposed for the  $V_1$  center in KCl. "Impurity" bands are found in "pure" and in Mg-doped LiH crystals. Bands due to Mg colloid and Z-type centers are found, along with a series of fine-structure lines like those previously reported only in LiF.

10,120 DEFECTS IN IRRADIATED SILICON. II. INFRARED ABSORPTION OF THE Si-A CENTER by J. W. Corbett, G. D. Watkins, R. M. Chrenko, and R. S. McDonald (GE Res. Lab.); Phys. Rev., Vol. 121, pp. 1015-1022, Feb. 15, 1961

Infrared measurements which, in conjunction with previously



## OPTICAL PROPERTIES (Cont'd)

reported spin resonance measurements, establish the identity of the radiation damage defect known as the Si-A center, are presented. A new infrared absorption band has been observed at  $12\mu$  in electron-irradiated silicon. This band is shown to be a vibrational band of impurity oxygen in the lattice. Macroscopic and microscopic correlations between the  $12\mu$  band and the spin resonance of the Si-A center are presented. The macroscopic correlations are of production rate, recovery, etc. The microscopic correlations derive from the absorption of polarized infrared radiation by samples of various crystallographic orientations, subjected to a uniaxial, compressive stress. Partial alignment of the defects is induced by the stress and is detected as a dichroism in the  $12\mu$  band. This alignment is compared to the corresponding alignment studies in spin resonance measurements. It is shown that the kinetics and magnitude of the response to the stress are the same for the defects observed in both types of measurements. This shows that the  $12\mu$  band arises from the Si-A center and established the configuration of the oxygen in the defect. These results indicate that the Si-A center is a lattice vacancy with an oxygen atom bridging two of the four broken bonds associated with the vacancy. The remaining two bonds can trap an electron, giving rise to the spin resonance spectrum of the defect. The identification of the Si-A center indicates that the vacancy is mobile in a room temperature irradiation.

10,121 THE EFFECT OF A STRONG ELECTRIC FIELD ON THE ABSORPTION OF LIGHT BY SILICON by V. S. Vavilov and K. I. Britsyn (Moscow State U.); Soviet Phys.-Solid State, Vol. 2, pp. 1746-1747, Feb. 1961

A shift of  $150\text{\AA}$  in the absorption band edge of monocrystalline Si when exposed to a constant external field of  $5 \times 10^4 \text{ v/cm}$  is discussed. The shift was observed with thin samples of Si, and is attributed to phonon participation in transitions from the valence to the conduction band. The magnitude of the shift and its dependence on the field intensity agree with theoretical predictions. The observed effect apparently has no inertia. A description and diagram of the experimental device are included.

10,122 BAND STRUCTURE OF NOBLE METAL ALLOYS: OPTICAL ABSORPTION IN Cu-Ge ALLOYS AT  $4.2^\circ\text{K}$  by J. A. Rayne (Westinghouse Res. Lab.); Phys. Rev., Vol. 121, pp. 456-461, Jan. 15, 1961

Calorimetric optical absorption measurements made at  $4.2^\circ\text{K}$  on a representative series of copper-germanium alloys, over the wavelength range 0.23 to 4 microns, using electropolished bulk specimens are reported. The variation of the infrared absorptivity with residual resistance for the dilute alloys confirms that the impurity relaxation time for copper is anisotropic. Changes in the absorption spectrum below  $6000\text{\AA}$  are inconsistent with the rigid band model, but may be reconciled with the theory of Cohen and Heine. The shift in the main absorption edge is analyzed to give information about the screening of the solute atoms in these alloys.

10,123 OPTICAL ABSORPTION OF CUPROUS OXIDE by P. W. Baumeister (U. Rochester); Phys. Rev., Vol. 121, pp. 359-362, Jan. 15, 1961

Measurements of the relative optical absorption coefficient  $\alpha$  of polycrystalline slabs of cuprous oxide at  $295^\circ\text{K}$ ,  $77^\circ\text{K}$ , and  $4.2^\circ\text{K}$  are reported. At  $4.2^\circ\text{K}$ ,  $\alpha$  is proportional to  $[\sigma - E_0]^{1/2}$  for  $16510\text{cm}^{-1} \leq \sigma \leq 16900\text{cm}^{-1}$ , where  $\sigma$  is the wave number.

At  $77^\circ\text{K}$  an additional component appears, so that  $\alpha = \alpha_1 + \alpha_2$ , with  $\alpha_1 \propto [\sigma - E_1]^{1/2}$  and  $\alpha_2 \propto [\sigma - E_2]^{1/2}$ . This is attributed to indirect transitions to exciton levels, in agreement with a theory by Elliott. The ratio of the integrated absorption coefficient of the first two exciton lines, after corrections for the background were applied, is also in satisfactory agreement with the Elliott theory.

10,124  $\alpha$  AND  $\beta$  BANDS IN SODIUM CHLORIDE by J. D. Rigden (Nat'l. Res. Council, Canada); Phys. Rev., Vol. 121, pp. 357-358, Jan. 15, 1961

Measurements of the peak energy of the  $\alpha$  and  $\beta$  bands in sodium chloride crystals made at  $77^\circ$  with a vacuum ultraviolet monochromator are reported. The  $\beta$  band was well defined, and occurred at 7.40 eV with a half-width of 0.4 eV. The oscillator strength of the  $\beta$  band is calculated to be 0.55. No resolved  $\alpha$  band could be produced, but subtraction of absorption curves indicated that it occurred near 7.20 eV.

Optical Absorption of  $\text{CdSnAs}_2$  - See 10,032

Optical Transmission in II-V Compounds - See 10,054

10,125 RECOMBINATION RADIATION FROM SILICON UNDER STRONG-FIELD CONDITIONS by L. W. Davies and A. R. Storm, Jr. (Bell Labs.); Phys. Rev., Vol. 121, pp. 381-387, Jan. 15, 1961

In an attempt to determine the distribution in energy of hot electrons and holes in silicon placed in an intense uniform electric field, measurements have been made of the spectral distribution of recombination radiation at  $77^\circ\text{K}$  (field strengths up to  $3700 \text{ v cm}^{-1}$ ) and at  $20^\circ\text{K}$ . No change in the spectrum with field was observed, other than a rise in temperature of  $6^\circ$  at  $77^\circ\text{K}$  due to Joule heating at  $3700 \text{ v cm}^{-1}$  in the sample, from which it was concluded that recombination radiation at these temperatures arises predominantly from the decay of excitons formed from the hot carriers, and that the excitons have a thermal distribution of energy at the lattice temperature. In addition, results are given for the spectrum of the radiation from avalanche breakdown regions in reverse-biased silicon p-n junctions at  $77^\circ$  and  $300^\circ\text{K}$ ; no differences were detected in the range of energies 1.0-1.4 eV, from which it was concluded that exciton decay does not contribute to the observed radiation at  $77^\circ\text{K}$ .

10,126 ELECTRONIC STRUCTURE OF THE CENTERS IN  $\text{ZnS}$  by J. L. Birman (U. Pennsylvania and Genl. Tel. Electronics Res. Labs.); Phys. Rev., Vol. 121, pp. 144-145, Jan. 1, 1961

A model of the common sulfide luminescent centers is proposed. The mutual perturbation of crystal eigenstates and transition-metal (activator) d eigenstates is assumed to give rise to the excited and unexcited eigenstates of the center. For substitutional  $\text{Cu}^+$  ( $d^{10}$ ) in zincblende, zeroth order crystal field theory predicts that two sets of occupied center ground-state levels ( $T_2$  and E) originating from  $d^{10}$  will exist. Additional level splittings result from (a) the spin-orbit effect, and (b) axial crystal field splittings in wurtzite. Experiments on visible and infrared, excitation and emission, are used to make tentative assignments of magnitude of level splittings.

10,127 ELECTROLUMINESCENCE OF ZINC SULFIDE SINGLE CRYSTALS by I. T. Steinberger, V. Bar, and E. Alexander (Hebrew U.); Phys. Rev., Vol. 121, pp. 118-124, Jan. 1, 1961

The results of a series of experiments designed to distinguish



## OPTICAL PROPERTIES (Cont'd)

between ionization and recombination processes during electroluminescence in which rectangular voltage pulses were applied to single crystals of zinc sulfide are reported. During the "on" period, the emission gradually increased to a stationary level. Removal of the voltage resulted in a burst of emission, which decayed slowly. This behavior is explained by the assumption of three field-dependent processes, namely: (a) ionization of centers in barrier regions; (b) sweeping out of the liberated electrons from the vicinity of the centers; (c) tunnelling of electrons into the barrier regions. It was found that for a considerable voltage range the product of the light-sum (measured during the "off" period) by the current was proportional to the stationary emission level during the "on" period. This proportionality strongly supports the model suggested. In many cases the current was found to be more strongly dependent on the voltage than the light sum. This result favors an ionization mechanism which is independent of the current. The model suggests furthermore an alternative explanation for the Neunhoffer-effect, i.e., the enhancement of the thermal glow by electric fields. The explanation does not involve an impact-ionization mechanism.

128 ON THE ELECTROLUMINESCENCE OF ZnS AT LOW VOLTAGES by K. Patek (Inst. Phys., Prague); *Czech. J. Phys.*, 11, 11B, No. 1, pp. 18-20, 1961

The possibility of explaining non-zero electroluminescence brightness below the minimum ionization voltage by the influence of thermal velocities of electrons is discussed. The derived voltage dependence of electroluminescence brightness agrees with previously reported measurements. [see abstract 150.]

129 THE SIGNIFICANCE OF THE TEMPERATURE DEPENDENCE OF FLUORESCENCE INTENSITY by C. H. Haake (Westinghouse); *J. Electrochem. Soc.*, Vol. 108, pp. 78-82, Jan. 1961

In some phosphors the fluorescence intensity increases with increasing temperature, reaches a maximum, and then decreases. This behavior arises from a competition of an increasing absorption for the exciting radiation and thermal quenching of the excited radiation. However, the slope of the initial rise of fluorescence and the temperature of the maximum also depend rather strongly on the thickness of the sample considered. Thin samples, i.e., those in which the penetrating exciting radiation is not absorbed completely, in comparison with thick samples exhibit a steeper slope and a maximum at higher temperature. If the phosphor is in powder form, the average particle size also influences the slope and the position of the maximum although generally to a lesser degree than the sample thickness. Experimental data are presented for magnesium fluorogermanate and magnesium fluoroarsenate, both activated with manganese.

130 THE WAVELENGTH DEPENDENCE OF QUANTUM EFFICIENCY AND ABSORPTION COEFFICIENT OF  $\text{ZnSiO}_3/\text{Mn}$  POWDER PHOSPHOR by I. Masuda (Tokyo Shibaura Electric); *Phys. Soc. Japan*, Vol. 16, pp. 105-107, Jan. 1961

The relation between the wavelength dependence of the absorption coefficient of  $\text{ZnSiO}_3/\text{Mn}$  powder phosphor and that of the quantum efficiency of fluorescence as well as the relation between the latter and the activator concentration are described. It has been found that the peak of the quantum efficiency is always at the longer wavelength side than that of the absorption coefficient, and that with decrease of man-

ganese concentration, the quantum efficiency becomes larger, and its curve sharper. A simple theory is presented to explain these facts.

10,131 SOME OPTICAL PROPERTIES OF POWDER AND CRYSTALLINE HALOPHOSPHATE PHOSPHORS by P. D. Johnson (GE Res. Lab.); *J. Electrochem. Soc.*, Vol. 108, pp. 159-162, Feb. 1961

Diffuse reflectivity and excitation spectra of powder and optical absorption of synthetic single crystal halophosphate phosphors which have been determined in the spectral region 1100-3000 Å are presented. Intrinsic optical absorption by the host lattice begins at approximately 1500 Å in fluoroapatite and 1570 Å in chloroapatite. Absorption in bands of manganese in fluoroapatite at 1600, 1750, and 2150 Å results in luminescence in the absence of antimony. Absorption due to antimony lies between 1600 and 2900 Å. The preparation and some optical properties of synthetic single crystals are described.

10,132 PHOTOCONDUCTIVE TIME CONSTANTS AND RELATED CHARACTERISTICS OF P-TYPE GOLD-DOPED GERMANIUM by T. P. Vogl, J. R. Hansen, and M. Garbuny (Westinghouse Res. Lab.); *J. Opt. Soc. Am.*, Vol. 51, pp. 70-75, Jan. 1961

Use of two different methods to measure the very short photoconductive time constants of p-type gold-doped germanium is described. The first is indirect, using the relationship between the magnitude of generation-recombination noise and carrier lifetimes. The second method is direct, employing a high-speed light-pulsing technique. If no other noise sources are important, the results of the indirect method approach those of the direct method as a lower limit. A combination of such time-constant measurements has been performed on a series of crystals in which impurity densities and carrier concentrations had been evaluated by Hall coefficient and conductivity measurements. From these data quantum yields of carrier generation, and cross sections for photon capture and carrier recombination were evaluated. The photon capture cross section of the 0.15 eV gold acceptor level at  $5\mu$  is  $1.3 \times 10^{-16} \text{ cm}^2$ , averaging  $0.9 \times 10^{-16} \text{ cm}^2$  for  $2-9\mu$ . The hole capture cross section by the  $\text{Au}^-$  ion in germanium was found to be  $2.3 \times 10^{-14} \text{ cm}^2$ .

10,133 PHOTOCONDUCTIVITY OF SILVER CHLORIDE CRYSTALS UNDER PULSED X-RAY IRRADIATION by A. E. Michel (Cornell U.); *Phys. Rev.*, Vol. 121, pp. 968-977, Feb. 15, 1961

Studies of the photoconductivity produced by irradiation with  $0.2\mu\text{sec}$  x-ray pulses in AgCl as a function of temperature (80-280°K), x-ray intensity and penetration, field strength, and crystal preparation, undertaken in order to obtain information about lifetimes and mobilities of electrons and holes, are reported. The measurements of electron lifetimes ( $\sim 1\mu\text{sec}$ ) and mobilities in air-grown crystals are in agreement with those reported in the literature. The photoconductive response can be described by assuming deep electron traps throughout the volume of the crystal and possibly a disturbed surface layer. No hole motion is observed below 250°K; above that temperature the schubweg per unit field is estimated at  $5 \times 10^{-8} \text{ cm}^2/\text{v}$ . The electron lifetime in crystals grown and annealed in He is much smaller than in the air-grown samples. Assuming the same mobility in both samples the lifetime at 80°K is  $3 \times 10^{-9} \text{ sec}$ . At higher temperatures the pulses show long tails, and between 200° and 280°K the saturation time varies exponentially with  $1/T$ . It is assumed that shallow traps exist ( $\sim 0.08 \text{ eV}$ ) in a thin surface region which otherwise has a long electron lifetime as compared with the bulk of the crystal. Measurements



on crystals doped with 20ppm  $\text{Cu}^+$  indicate that the  $\text{Cu}^+$  ions do not act as effective electron traps. On the other hand, the presence of 1ppm Ni ions reduces the lifetime at  $80^\circ\text{K}$  to less than  $3 \times 10^{-11}\text{sec}$ , indicating a capture cross section of the Ni ion larger than  $300(\text{\AA})^2$ .

10,134 INFRARED ENHANCEMENT AND QUENCHING OF PHOTOCONDUCTION IN SINGLE CRYSTALS OF  $\text{ZnS}:\text{Cu}$  by F. G. Ullman and J. J. Dropkin (Polytech. Inst. Brooklyn); *J. Electrochem. Soc.*, Vol. 108, pp. 154-159, Feb. 1961

Observation of an ohmic infrared photoconductivity peaking at 0.65 and  $1.35\mu$  at room temperature in synthetic single crystals of  $\text{ZnS}:\text{Cu}$  is reported. The photocurrents are constant with time, not dependent on any previous excitation, and linear with intensity. With simultaneous 3650  $\text{\AA}$  ultraviolet (UV) and infrared (IR) the resultant photocurrents are less than the sum of the separate UV and IR photocurrents as measured independently. The spectral dependence of this so-called "quenching" and also of the IR absorption are similar to that of the IR photoconductivity (as well as to quenching and stimulation spectra reported for  $\text{ZnS}:\text{Cu}$  powder phosphors elsewhere). If each of these is assumed to arise from the same transition, the quenching phenomenon can be interpreted to be an electron-carrier UV photocurrent quenched by a hole-carrier IR photocurrent as in a Schoen-Klasens model. Both the IR photocurrent and the IR quenching decrease sharply at low temperatures and apparently require thermal activation.

10,135 INDUCED INFRARED PHOTOSENSITIVITY IN CERTAIN SEMICONDUCTORS by E. N. Arkad'eva and S. M. Ryvkin (Physicotech. Inst.); *Soviet Phys.-Solid State*, Vol. 2, pp. 1704-1705, Feb. 1961

Induced infrared (2 to 4 microns) photosensitivity in cadmium selenide, cadmium telluride, and antimony selenide, all at  $85^\circ\text{K}$ , is discussed. The photosensitivity was observed after preliminary illumination with visible light in the intrinsic absorption region. The spectral distribution of photoconductivity, as well as its time dependence, is shown for each compound. For cadmium telluride, a very pronounced excitation corresponding to an induced photoconductivity value which remained practically constant for several hours was noted.

10,136 DEPENDENCE OF THE PHOTOCONDUCTIVITY AND THE INTENSITY OF LUMINESCENCE OF ANTHRACENE CRYSTALS ON THE EXCITATION WAVELENGTH by V. V. Eremenko and V. S. Medvedev; *Soviet Phys.-Solid State*, Vol. 2, pp. 1426-1428, Jan. 1961

The dependence of photoconductivity and the intensity of luminescence on excitation wavelength are evaluated concurrently. The same crystal was used to obtain both curves. The technique permitted measurement of luminescent intensity when the exciting light was incompletely absorbed. Diffusion length calculated from the dependence both of quantum yield of luminescence and the magnitude of photocurrent on absorption coefficient were similar. Since coincidence of diffusion lengths of excitons and of free carriers is unlikely, the diffusion of excitons toward the sample surface is proposed as the reason for the spectral response of photoconductivity.

Effect of Photoexcitation on the Mobility in Photoconducting Insulators - See 10,070

Photoelectric Emission from  $\text{MgO}$  - See 10,085

10,137 PHOTOELECTRIC PROPERTIES OF ALLOY P-N JUNCTIONS IN SILICON CARBIDE by G. F. Kholuyanov (Ul'yanov Electrotech. Inst.); *Soviet Phys.-Solid State*, Vol. 2, pp. 1722-1726, Feb. 1961

Photoelectric response characteristics of alloy p-n junctions in  $\alpha\text{-SiC}$  are evaluated. Illumination was from the p-side of the junction. At room temperature, maximum response is for photon energy ranging from 4.3 to 4.5 eV; increasing the temperature shifts the response towards lower photon energy values, accompanied by a reduction in the forbidden band width. Short-circuit currents rise linearly with increasing temperature. The photo-emf at room temperature is 1.2 v for an illumination of  $5\text{mw}/\text{cm}^2$ . Reasons for the low photosensitivity of this compound are discussed.

10,138 THE EFFECTS OF GAMMA RADIATION ON SOLIDS. EXO-ELECTRON EMISSION FROM IRRADIATED IRON OXIDE CATALYSTS by E. J. Gibson (Warren Spring Lab.); *J. Phys. Chem. Solids*, Vol. 17, pp. 220-228, Jan. 1961

The results of an exploratory study into the emission of exoelectrons from powdered iron oxide catalysts for the Fischer-Tropsch synthesis after exposure to gamma radiation are presented. The evidence supports the theory that emission centres consist of oxygen ion vacancies containing trapped electrons. The role of irradiation appears to be the filling of the vacancies with electrons.

Photoelectric Emission of Si Treated in Cs Vapors - See 10,088

10,139 PHOTOCAPACITANCE EFFECTS IN ADDITIVELY COLORED ALKALI HALIDE CRYSTALS by D. Kahn and A. J. Glass (RIAS); *J. Phys. Chem. Solids*, Vol. 17, pp. 210-219, Jan. 1961

It is reported that when additively colored alkali halide crystals are placed between current blocking electrodes, an increase in the capacitance and conductance of the crystal is found on illumination. A measurement of these quantities at frequencies between 2 and 1000 c/s has shown that the observed behavior follows quite closely a linearized theory developed by J. Ross Macdonald. The region of application of the theory has been examined experimentally, and results show that the theory may be used for larger applied voltages than assumed in the theory. An analysis of the experimental data indicates that the field induced electrode breakdown for the larger voltages ( $\sim 5\text{V r.m.s.}$ ) is of such a nature that the equivalent circuit describing the crystal continues to be valid. Using the results of the theory the mobility of KI and KBr crystals at room temperature has been measured. These determinations agree substantially with measurements by others using Hall effect methods. Measurements at low frequencies have revealed phenomena due to the finite recombination rate of the conduction electrons and ionized F-centers. Analysis of this behavior gives as the capture cross section of an ionized F-center in KBr  $3.1 \times 10^{-15}\sqrt{\gamma}\text{cm}^2$ , where  $\gamma$  is the ratio of the effective electron mass (polaron) to the free electron mass. The recombination rate constant in KBr has also been measured.

Faraday Rotation Due to Interband Transitions in InAs and GaAs - See 10,068



10,140 CORRELATION EFFECTS ON THE ELECTRONIC SPECIFIC HEAT OF SODIUM by E. A. Stern (U. Maryland); Phys. Rev., Vol. 121, pp. 397-402, Jan. 15, 1961

The effect of the martensitic transformation in sodium on measured values of its specific heat is analyzed. It is shown that the only important effect at low temperatures is to produce a mixture of the two phases. The measured specific heat is very closely given by the sum of the specific heats of each phase measured separately. An analysis of the various experimental measurements gives the result that the effective mass of conduction electrons in the bcc high-temperature phase is greater than 1.5 times the free electron mass while in the hcp low-temperature phase the corresponding value is less than 1.21. Using further experimental data it is estimated that the effective masses in the bcc high-temperature phase and the hcp low-temperature phase are 1.7 and 1.1 times the free electron value, respectively. These effective mass values imply that there is substantial contact of the Fermi surface in the hcp structure with the "A" faces of the Brillouin zone. The large effective mass in the bcc phase indicates a large enhancement of the specific heat of the conduction electrons in sodium by correlation and electron-phonon interaction effects. The correlation effects alone appear to increase the specific heat of a free electron gas at a density corresponding to  $r_s = 3.96$  (in units of the Bohr radius) by about 40 per cent.

10,141 HEAT CAPACITY OF FERROMAGNETIC SUPERCONDUCTORS by N. E. Phillips (U. California) and B. T. Matthias (Bell Labs.); Phys. Rev., Vol. 121, pp. 105-107, Jan. 1, 1961

Heat capacity measurements on two samples from each of the systems  $La_{1-x}Gd_x$  and  $Y_{1-x}Gd_xOs_2$  that show features which are correlated with the reported existence of both ferromagnetic and superconducting transitions are reported. For one sample the measurements cover a wide enough temperature range to show that the entropy associated with the ordering of the gadolinium spins is the  $xR \ln 8$  expected for complete order. The heat capacities of the other samples are consistent with complete ordering. Superconducting transitions have been observed both above and below the maximum in the heat capacity associated with the spin ordering. The entropy differences between the normal and superconducting states show that superconductivity is not confined to small volume elements but probably extends throughout the sample.

10,142 THEORETICAL BOUND ON THE THERMOELECTRIC FIGURE OF MERIT FROM IRREVERSIBLE THERMODYNAMICS by H. Littman and B. Davidson (Syracuse U.); J. Appl. Phys., Vol. 32, pp. 217-219, Feb. 1961

The principles of irreversible thermodynamics are used with an idealized model to derive Joffe's dimensionless "figure of merit,"  $T\alpha^2\sigma/(\kappa)_2 = 0$ , and a theoretical upper bound of infinity.

10,143 CONCERNING A RAPID METHOD OF PRECISE MEASUREMENTS OF THERMAL EMF OF SEMICONDUCTORS by O. V. Emel' Hanenko and F. P. Kesamanly (Inst. Phys. Tech., Leningrad); Soviet Phys.-Solid State, Vol. 2, pp. 1356-1358, Jan. 1961

A device employing contact thermocouples but suppressing temperature differences between the semiconductor surface and the thermocouple junction under steady state conditions is

described. Two thermocouples are used at each of the two points of measurement on the semiconductor. One thermocouple junction of each pair contacts the surface; the other is just above the surface. Each pair is heated by a coiled heater as close to the junctions as possible, and the heat input is adjusted to eliminate any current between the thermocouples. This indicates temperature uniformity between the surface and the thermocouple junction in contact with it.

10,144 THE EFFECT OF FREEZING CONDITIONS ON THE THERMOELECTRIC PROPERTIES OF  $BiSbTe_3$  CRYSTALS by J. P. McHugh, G. J. Cosgrove, and W. A. Tiller (Westinghouse Res. Labs.); 1961 Symp. Thermoelectric Energy Conversion

An investigation of the effects of growth rate and interface temperature gradient on the thermoelectric parameters  $\alpha$ ,  $1/\rho$  and  $1/(K - K_e)$  using Bridgman grown, oriented polycrystals of  $BiSbTe_3$  was discussed. All four parameters were found to increase as the freezing rate decreases and the temperature gradient in the liquid at the interface increases. The effects are primarily attributed to the variation in the degree of micro-segregation produced in the crystals by the freezing condition.

Effect of Pressure on the Seebeck Coefficient of  $NiO$ ,  $CoO$ ,  $CuO$ , and  $Cu_2O$  - See 10,075

Seebeck Coefficient of  $Ag_2Te$  - See 10,061

10,145 THERMOELECTRIC PROPERTIES OF THE INTERMETALLIC COMPOUND  $MnAl_3$  by N. V. Kolomoets and A. E. Popova (Semicon. Inst.); Soviet Phys.-Solid State, Vol. 2, pp. 1758-1761, Feb. 1961

The preparation and thermoelectric properties of  $MnAl_3$ , as well as the experimental technique used, are discussed. A thermoelectric power maximum of  $+70 \mu V/deg$  was obtained. The negative sign of thermoelectric power in the intrinsic conductivity region indicates greater mobility (over  $200 cm^2/v\text{-sec}$ ) of electrons than of holes. The forbidden-band width was found to be approximately 0.58 eV. The temperature dependences of electrical conductivity and thermoelectric power are plotted between  $300^\circ$  and  $1100^\circ K$  for five samples.

Thermoelectric Properties of Li or Na Doped  $MnTe$  - See 10,020

Thermoelectric Properties of Some II-IV Compounds - See 10,036

10,146 PULSE METHOD FOR THE MEASUREMENT OF THERMAL DIFFUSIVITY OF METALS by E. L. Woisard (Lehigh U.); J. Appl. Phys., Vol. 32, pp. 40-45, Jan. 1961

A pulse method for measuring the thermal diffusivity of metals is described. The temperature in an effectively infinite rod is zero everywhere up to the time  $t = 0$ ; a very short heat pulse is then introduced in the plane  $x = 0$ . The subsequent temperature histories of several points at different distances from  $x = 0$  are recorded, and from these data the thermal diffusivity may be calculated. Since an experimental run lasts less than one minute, the requirements on the stability of the ambient temperature are not as stringent as in previously reported methods. This method saves time without sacrificing accuracy, a maximum error of  $\pm 4\%$  being estimated. Although all work has been done at room temperature, the specimens are mounted in a vacuum furnace which should permit measurements at elevated temperatures. The method was tested on commercial "A"



## THERMAL PROPERTIES (Cont'd)

nickel, giving a result in excellent agreement with previous values. Results are reported for four new steels developed by the Bethlehem Steel Company.

Thermal Properties of  $\text{Bi}_2\text{Te}_3$  - See 10,030

Thermal Properties of Sm-S Compounds - See 10,037

## MECHANICAL PROPERTIES

10,147 NOTES ON A HIGH PRESSURE GAS APPARATUS by D. Langer and D. M. Warschauer (Wright Air Dev. Ctr.); Rev. Sci. Instr., Vol. 32, pp. 32-35, Jan. 1961

A hydrostatic high pressure apparatus capable of achieving 18 kilobars at room temperature, 14.1 kilobars at  $77^\circ\text{K}$ , and limited in pressure at lower temperatures only by the freezing of helium is described. A number of techniques facilitating construction, operation, and repair are considered. An experimental pressure vessel and cryostat for optical studies to 16 kilobars in the temperature range from  $370^\circ$  to approximately  $60^\circ\text{K}$  are also discussed.

10,148 DISLOCATION CONTRIBUTIONS TO THE MODULUS AND DAMPING IN COPPER AT MEGACYCLE FREQUENCIES by G. A. Alers (Ford Motor) and D. O. Thompson (Oak Ridge Natl. Lab.); J. Appl. Phys., Vol. 32, pp. 283-293, Feb. 1961

Measurements of the three elastic moduli of 99.999+ per cent pure copper and their associated internal frictions at Mc frequencies between 4.2 and  $250^\circ\text{K}$  both before and after neutron bombardment are reported. The changes produced by the irradiation were used to determine the dislocation contributions to the damping and moduli as a function of frequency and temperature. The dislocation damping showed the maximum predicted by Granato and Lücke to arise from the heavily damped bowing of dislocation loops. By calculating the resolved shear stress factors and measuring the dislocation density by etch pit counts, it was possible to determine the coefficient B which describes the viscous drag on a moving dislocation as well as the effective loop length  $l$ . The factor B was found to be  $8 \times 10^{-4} \text{dsec/cm}^2$  at  $300^\circ\text{K}$  and to decrease linearly with decreasing temperature, as predicted by Leibfried. The effective loop length appeared temperature independent and had a value of  $3 \times 10^{-4} \text{cm}$  in the sample examined most carefully. Cold-worked single crystals of the same copper were also studied. Two Bordoni type peaks in the damping vs temperature curves were located at  $135^\circ$  and  $60^\circ\text{K}$  at 10 Mc. Activation energies of 0.113 and 0.05 ev were determined by using low-frequency data taken from the literature.

10,149 ELASTIC CONSTANTS OF CsBr FROM  $4.2^\circ\text{K}$  TO  $300^\circ\text{K}$  by B. J. Marshall (Rice U.); Phys. Rev., Vol. 121, pp. 72-73, Jan. 1, 1961

Measurements of the elastic constants of single crystals of cesium bromide from  $4.2^\circ\text{K}$  to  $300^\circ\text{K}$  are reported. The values of the elastic constants at  $4.2^\circ\text{K}$  are  $c_{11} = 3.350 \pm 0.8\%$ ,  $c_{12} = 1.025 \pm 10\%$ , and  $c_{44} = 1.002 \pm 0.8\%$  in units of  $10^{11} \text{dynes/cm}^2$ . The Debye temperature ( $\theta_D$ ) at  $0^\circ\text{K}$  as calculated from the elastic constants is  $149.0^\circ\text{K} \pm 2^\circ\text{K}$ . The lattice energy at  $0^\circ\text{K}$  is computed to be  $U_0 = 147.6 \text{kcal/mole}$ .

10,150 PULSE SUPERPOSITION METHOD FOR MEASURING ULTRASONIC WAVE VELOCITIES IN SOLIDS by H. J. McSkimin (Bell Labs.); J. Acoust. Soc. Am., Vol. 33, pp. 12-16, Jan. 1961

The frequently used pulse method of measuring ultrasonic wave velocities in solids involves a high-frequency quartz crystal transducer cemented to one end of a specimen having parallel end faces. The phase shift for waves reflected from the transducer must be considered for highest accuracy. It is shown that combining several measurements of phase delay (at two frequencies differing by approximately 10 per cent) with a theoretical analysis of the reflection phase angle makes possible a determination of velocity to within one part in 5000 for round-trip delays greater than  $5 \mu\text{sec}$ . Indirectly, the approximate thickness of the cement bond between transducer and specimen can be determined. The advantages of the method for making measurements as a function of temperature or pressure are discussed.

10,151 ORIGIN OF HYPERSONIC ATTENUATION IN GERMANIUM AT LOW TEMPERATURES by G. S. Verma and S. K. Joshi (U. Allahabad); Phys. Rev., Vol. 121, p. 396, Jan. 15, 1961

Hypersonic attenuation in germanium at different temperatures is calculated and compared with the recent low-temperature measurements by Truell and his associates. The excellent agreement between the theory and experiment for the temperature dependence shows that Umklapp processes are responsible for the attenuation at low temperatures.

## SOLID STATE DEVICES

### DIODES

10,152 HIGH-SPEED AUTOMATIC DIODE TESTER by E. V. Marrott and V. S. Zucco (IBM); Electronics, Vol. 34, pp. 93-95, Jan. 13, 1961

The testing of ten diode parameters using plug-in test packs on a high-speed automatic tester which rejects faulty diodes immediately following detection is described. The test packs are interchangeable for both manual and automatic testing. Test parameters available are back resistance, forward voltage drop, peak inverse voltage, dynamic back resistance, forward recovery, flutter, low Zener voltage, high Zener voltage, Zener impedance and hysteresis. These parameters are divided into the categories of constant voltage, constant current, and ac tests. Testing rate is 18,000 high usage diodes per day automatically and 1,200 relatively low usage diodes per day manually. A conveyor belt moves the diodes past adjacent sets of brush contacts in each test pack.

10,153 THE MEASUREMENT OF TUNNEL DIODE JUNCTION CAPACITANCE by U. S. Davidsohn (GE); Proc. IRE, Vol. 49, pp. 372-373, Jan. 1961

A test circuit for measuring the capacitance of tunnel diodes over a large range of peak-point currents and  $g/c$  ratios is



scribed. The circuit measures the sum of junction and distributed capacitance over a small range of voltages around the knee voltage. Difficulties encountered with previous testing devices, which could be stabilized only in limited current ranges and which introduced large lead inductance errors, are minimized through the use of a switching load line to bias the diode and force stability. A variable bias is also used to adjust the intercept point on the diode characteristic so that the bridge measures a parallel positive resistance of 1 K or greater, thus reducing the lead inductance error to 0.2  $\mu\text{f}$  or less.

10,154 CHARACTERIZATION OF MICROWAVE VARIABLE CAPACITANCE DIODES by S. T. Eng (Hughes Semicon. Div.); IRE Trans., Vol. MTT-9, pp. 11-22, Jan. 1961

The electrical characterization of microwave variable capacitance diodes is discussed. The importance of some of the diode parameters is considered from the application point of view, and suitable measurement techniques for these parameters are described, together with actual measurement data on some diodes. First, a general four-terminal transformation method is used, and some approximations lead to a fairly easy and accurate method of studying device characteristics. A resonant-cavity method is also considered, and it is explained under what condition it leads to a very simple test of the diode Q. Finally, a method based upon modifications of the Weissfloch canonical network is presented. These simplifications can be used to get an easy interpretation of the junction impedance of the diode Q.

Silicon Mesa-Varactor Diode - See 10,224

10,155 GALLIUM-ARSENIDE POINT-CONTACT DIODES by W. M. Sharpless (Bell Labs.); IRE Trans., Vol. MTT-9, pp. 6-10, Jan. 1961

The properties of gallium arsenide as a material for point-contact diodes are considered. By controlling the resistivity of the gallium arsenide and the point-contact processing techniques, diodes have been fabricated specifically for use as millimeter wave first detectors, high-speed switches, and reactive elements for microwave parametric oscillators and amplifiers. The operating characteristics of several different types of gallium-arsenide reactive diodes are discussed and simple design formulas which may be used to tentatively evaluate the performance to be expected from such diodes are mentioned. Noise figure measurements are included in a résumé covering some of the experimental results that have been obtained using gallium-arsenide point-contact diodes as variable reactance elements in microwave parametric amplifiers.

10,156 CONSTRUCTION AND CHARACTERISTICS OF SILVER-BONDED DIODES by S. Kita (Nippon Tel. and Tel.); Rev. Electr. Comm. Labor., Vol. NTT-9, pp. 26-30, Jan.-Feb. 1961

A silver-bonded diode designed for use in parametric amplifiers is described. The diode is produced by the following process: the tip of a silver whisker containing a small amount of gallium is brought into contact with an n-type germanium wafer and electrically formed. The impedance of the diode has been measured with a coaxial type standing wave detector at room temperature and at 100°K. The minimum barrier capacitance is about 0.1 pF, the series resistance 10 ohms, and the cutoff frequency at breakdown voltage 200 GC. [see also abst. 10,225]

10,157 CURRENT-VOLTAGE CHARACTERISTICS OF FORWARD BIASED LONG P-I-N STRUCTURES by R. D. Larrabee (RCA Labs.); Phys. Rev., Vol. 121, pp. 37-39, Jan. 1, 1961

Observations of the current-voltage characteristics in several germanium p-i-n structures with the n side biased negative and the p side positive so as to cause a double injection of electrons and holes into the structure are reported. The middle i section was constructed of good quality germanium (approximately  $2 \times 10^{13}$  donors/cm<sup>3</sup>) and was many minority carrier diffusion lengths long. The observed I-V characteristics display a low-field region in which the current is proportional to the voltage, followed by a higher field region in which the current is proportional to the square of the voltage. In the square-law region, the current is a function of the difference, rather than the sum, of the thermal densities of the electrons and holes. These observations lend experimental support to the basic theories of Lampert and Rose regarding volume-controlled double injection into a semiconductor.

Theory of Tunneling - See 10,089

10,158 TUNNELING CURRENT IN ESAKI DIODES by C. W. Bates, Jr. (Avco); Phys. Rev., Vol. 121, pp. 1070-1071, Feb. 15, 1961

The integral giving the net tunneling current flowing across the junction in an Esaki diode,

$$I = A \int_{E_c}^{E_v} \{f_c(E) - f_v(E)\} Z \rho_c(E) \rho_v(E) dE$$

is evaluated under the normal assumptions that  $(\xi_c - E_c)$  and  $(E_v - \xi_v)$  are of the order of 2kT. The resulting expression is

$$I = -A'' \frac{(E_v - E_c)^2 (1 - e^{qV/kT})}{(m+n)e^{a/2} + (1 + e^{qV/kT})}$$

where A'' is an arbitrary constant and m, n, and a are functions of the Fermi levels on both sides of the junction, the location of the band edges and the absolute temperature. This expression is plotted as a function of the applied voltage for temperatures of 200°K, 300°K, and 350°K for donor and acceptor concentrations of  $10^{19}$  cm<sup>-3</sup> and  $1.6 \times 10^{19}$  cm<sup>-3</sup>, respectively. The resulting curves compare quite favorably with those of Esaki's.

10,159 EXCESS TUNNEL CURRENT IN SILICON ESAKI JUNCTIONS by A. G. Chynoweth, W. L. Feldmann, and R. A. Logan (Bell Labs.); Phys. Rev., Vol. 121, pp. 684-694, Feb. 1, 1961

A comprehensive experimental study of the excess tunnel current in silicon junctions is reported. It is shown that the properties of the excess current observed so far can be accounted for by a mechanism originally suggested by Yajima and Esaki, in which carriers tunnel by way of energy states within the forbidden gap. Based on this model, the following expression for the excess current,  $I_x$ , is proposed:

$I_x \sim D_x \exp \{ - (\alpha_x W_1 e^{1/2} / 2) [\epsilon - eV_x + 0.6e(V_n + V_p)] \}$ , where  $D_x$  is the density of states in the forbidden gap at an energy related to the forward bias,  $V_x$ , and the Fermi energies on the n and p sides are  $V_n$  and  $V_p$ , respectively,  $e$  is the electron charge,  $\epsilon$  is the energy gap,  $W_1$  is the junction width constant, and  $\alpha_x$  is a constant containing a reduced effective mass,  $m_x$ . This formula describes the observed dependence of  $I_x(i)$  on  $D_x$ , observed by introducing states associated with



## DIODES (Cont'd)

electron bombardment, (ii) on  $\epsilon$ , studied by the temperature variation of the diode characteristics, (iii) on  $V_x$ , verified from semilogarithmic plots of the forward characteristics, and (iv) on  $W_1$ , tested by using junctions of different widths. From these experiments,  $m_x = 0.3m_0$  to within a factor of 2. The origins of the states in the band gap are not known for certain though they are most likely the band edge tails inherent to heavily doped semiconductors. It is probable that the tunneling-via-local-states model for the excess current in silicon is applicable to excess currents in other materials.

10,160 SHIFT OF PEAK VOLTAGE WITH TEMPERATURE IN TUNNEL DIODES by R. P. Nanavati (Syracuse U.); Proc. IRE, Vol. 49, p. 349 (L), Jan. 1961

The effect of temperature change on the peak voltage of certain tunnel diodes is noted. Shifts of from 15 to 70 per cent of room temperature peak voltage have been observed in germanium, silicon, and gallium-arsenide tunnel diodes. Possible contributing factors to this phenomenon are shifts in the Fermi level, change in tunneling probability, and broadening of the band gap at lower temperatures.

10,161 ON THE STABILITY OF ESAKI DIODE CIRCUITS [in Japanese] by H. Fukui (Sony); J. Inst. Elect. Commun. Engrs. Japan, Vol. 44, pp. 55-62, Jan. 1961

The transient characteristics of Esaki diodes are explained by solving linearized differential equations based on the investigation of a small signal equivalent circuit. The use of a P-Q plane, with the circuit parameters taken as the axes, facilitates the investigation. The basic concepts for the determination of circuit parameter values in various applications are established. As an example, the stability conditions required for the measurement of the current-voltage characteristics are determined. In general when an Esaki diode oscillates without satisfying the stability conditions an anomalous curve which has not been explained satisfactorily is observed in the current-voltage characteristics. The idea of self-bias in oscillation is introduced and it is shown that this phenomenon can be understood by investigating the locus of a representative point on the P-Q plane.

Backward Diodes - See 10,308

10,162 FORWARD CURRENT-VOLTAGE CHARACTERISTICS OF A BARRIER LAYER IN A GERMANIUM P-N JUNCTION by F. M. Berkovskii, S. M. Ryvkin, and N. B. Strokan (Physicotech. Inst.); Soviet Phys.-Solid State, Vol. 2, pp. 1762-1767, Feb. 1961

The forward I-V characteristics of a P-N junction at high current densities (up to 1000 amp/cm<sup>2</sup>) are evaluated. The results were obtained by separating the effects of voltage across the space charge region from that across the rest of the diode, according to the difference in relaxation rate of the two components of voltage, and including a correction for bulk-concentration (Dember) emf. Saturation was achieved at current densities of about 100 amp/cm<sup>2</sup> or greater; in such cases, however, the junction saturation voltage was less than the contact voltage by 60 to 70 mv. The experimental technique and results are described in detail.

10,163 PROBLEMS RELATED TO P-N JUNCTIONS IN SILICON by W. Shockley (Shockley); Solid-State Electronics,

Vol. 2, pp. 35-67, Jan. 1961

The phenomena of secondary ionization, avalanche breakdown, and microplasma phenomena in p-n junctions are analyzed using a simplified model in which holes and electrons have identical properties described by four constants. Only two scattering processes for carriers are considered, each having two constants; i.e., generation of highest energy or Raman phonons (energy  $E_R$  and mean-free-path  $L_R$ ) and ionization or electron-hole pair production (threshold carrier energy  $E_i$  and mean-free-path  $L_i$ ).  $E_R$  has been determined from neutron scattering data; its value is 0.063 ev for Si and 0.037 ev for Ge. The other three constants are adjustable.  $E_i$  and  $L_i/L_R = r$  are chosen to fit data on quantum yield for photons with  $1 < h\nu < 5$  ev using the formula  $Q = 3 - 2 \exp(E_g + 2E_i - h\nu)/2rE_R$ . For silicon this gives  $E_i = 1.1$  ev (which is equal to the energy gap  $E_g$ ) and  $r = 17.5$ . For germanium  $E_i$  is also about 1.1 ev and  $r = 57$ . The simple model predicts that the ionization coefficient  $\alpha(F)$  varies with field  $F$  as  $(qF/rE_R) \exp - (E_i/qL_RF)$  which is in good agreement with Chynoweth's data for electrons in silicon if  $L_R$  is set equal to 50 Å. The model predicts an energy per pair for ionization by high-energy particles of about  $2.2E_i + rE_R$  which is in good agreement with measured values. It also predicts a hot-carrier random energy of about 0.2 ev for  $F = 400,000$  v/cm, which agrees with the spectra of hole-electron recombination in microplasmas. Thus the three adjustable constants permit fitting six pieces of experimental data in four independent experiments in spite of the fact that the intricacies of the band structure are disregarded. The effects of statistical spatial fluctuations of donor and acceptor ions are considered and it is concluded that these will be randomly distributed according to a Poisson distribution. This randomness leads to a characteristic fluctuation voltage  $(qF_B/K)^{1/2} \approx 0.3$  v for silicon where  $F_B$  is the breakdown field, and the dielectric constant  $K = 1.04 \times 10^{-12}$  F/cm for silicon. The effect of these fluctuations is to produce local regions in a p-n junction with breakdown about 0.7 v lower than the average in uncompensated material. The fluctuations of voltage are larger by  $[(N_d + N_a)/(N_d - N_a)]^{1/2}$  in compensated material. The fluctuations can increase the apparent ionization coefficient substantially. Microplasma effects are considered and it is shown that in a junction with only the Poisson fluctuations the microplasma should be stabilized by an apparent series resistance due to space charge of magnitude  $1/\nu_{\max} K \approx 10^5 \Omega$  where  $\nu_{\max} = (E_R/m^*)^{1/2}$  is the limiting drift velocity. This is much larger than the spreading resistance term of magnitude  $1/\mu F_B K \approx 2000 \Omega$ . It is concluded that typical noisy microplasma phenomena are probably associated with localized structural defects probably having two characteristics: (1) they increase the effective ionization coefficient to a value greater than  $10^5$  cm<sup>-1</sup> over a region less than  $10^{-5}$  cm long; (2) they have a mechanism for capturing charge which increases the field once the microplasma has formed. Small SiO<sub>2</sub> precipitates and dense arrays of dislocations appear to have the requisite properties. Metal precipitates in the space-charge layer produce "soft" reverse characteristics with localized currents of the form  $\sqrt{e \pm 1}$ .

Photoelectric Properties of PN Junctions in SiC - See 10,137

10,164 SEALED CRYSTAL DIODE PACKAGES by F. J. Bourassa (Raytheon); U.S. Pat. 2,969,487, Issued Jan. 24, 1961

A coaxial package design that enables a diode chip to be re-etched if tests indicate the necessity is described. The package consists of a stem to which the chip is soldered and a can which is soldered onto the stem to seal the unit. By demounting the



from the stem, the chip can be re-etched. This design provides an advantage over the glass diode package which cannot be disassembled for re-etch.

165 PIN MATERIAL FOR GLASS SEAL SEMICONDUCTOR RECTIFIER by A. N. Sahagun (PSI); U.S. Pat. 2,970,248, Issued Jan. 31, 1961

Electrode material of a silver base alloy for use in coaxial diode packages is discussed. By the addition of indium, lithium, and zinc to copper-silver alloys improvements in workability and brazing characteristics are obtained over previously used materials. The addition of lithium makes the alloy self-fluxing, and helps to getter out any contaminants which are present. Brazing of the alloy to kovar occurs at a lower temperature ( $550^{\circ}\text{C}$ ) and the resultant seal contains no brittle compounds that would be subject to thermal or mechanical failure.

Increasing the Heat Dissipation of Diode Structures - See 10,183

## TRANSISTORS

166 SWITCHING TRANSISTORS by C. W. Mueller and E. Barton (RCA); U.S. Pat. 2,968,751, Issued Jan. 17, 1961

Procedures for the manufacture of a germanium p-n-p switching transistor and the application of the device as a switch, block-oscillator, and frequency divider are discussed. Conventional techniques are employed in fabrication. Emphasis is placed upon the lead-tin-indium collector contact solder; variations in indium content affect the triggering current required from the base. The device can be pulsed to the "on" and the "off" conditions; rise time is in the order of 0.1 microseconds and fall time varying from 0.04 microseconds at 20 volts to 0.01 microseconds at 8 volts.

167 MEASURING PARAMETERS BY POWER TRANSISTOR TEST TECHNIQUES by D. Breslow (Baird-Atomic); Electronics, Vol. 34, pp. 120-122, Jan. 6, 1961

Theory and instrumentation of pulse or sweep-type methods of testing high power transistors are discussed. The basic method of pulse testing is to apply biases to the test transistor such that the current is drawn in pulses of high peak value, but of sufficiently low duty cycle that the average power and resulting heating is small. Detection of the transistor's response signals are made and the dc parameters are obtained. These measurements are equivalent to those made by conventional dc. The purposes of pulse-type testing are to minimize the requirements for heat sinks, to reduce stress on the test transistor, to achieve tests possible under dc conditions, and to evaluate the transistor under switching conditions.

Use of NPNP Switches as Storage Elements in Shift Registers - See 10,186

168 DETERMINATION OF PHYSICAL PARAMETERS OF DIFFUSION AND DRIFT TRANSISTORS by M. B. Das and R. Boothroyd (Imperial Coll.); IRE Trans., Vol. ED-8,

pp. 15-30, Jan. 1961

The dynamic properties of drift and diffusion transistors are studied under both low- and high-level injection conditions in terms of the excess carrier charge in the base region. Subject to the assumptions of effectively one-dimensional device geometry with exponential impurity grading and collector conductivity much greater than that of the base, methods of determining the main physical and high-frequency equivalent-circuit parameters of transistors are presented, utilizing the bias dependence of excess carrier charge in the base and space charge in the collector-depletion region. It is shown that measurement of the base transit time and the junction capacitances under low-level injection conditions enables the following physical parameters to be determined: base field parameter  $m = \Delta V / (kT/q)$ , base width, base impurity distribution, emitter area, collector-depletion layer width. All the measurements are carried out at relatively low frequencies. Solutions for the base charge distribution, and hence charge-defined transit time, have been derived for the cases of exponential and erfc impurity grading under high-level injection conditions, assuming one-dimensional device geometry, constant base cross-sectional area, and  $D$  and  $\mu$  independent of injection level. Experimental results have been found to differ greatly from the theoretical expectations based on these assumptions, the drift transistor showing greater and the diffusion transistor less than the predicted dependence on injection level. Explanations for the observed effects are given in terms of reduction of emitter area and of  $D$  and  $\mu$  at high injection levels.

10,169 THEORETIC CURVES OF DRIFT TRANSISTOR CURRENT GAIN by G. E. Terner (IBM); IRE Trans., Vol. ED-8, pp. 13-15, Jan. 1961

A simplified approximation equation for the intrinsic common-base, short-circuit current gain analysis of drift transistors is given. The accuracy of the equation may be controlled by the investigator. A graphic solution for determining this parameter of moderate drift field transistors may be obtained by using the arcs of circles. The interrelation between the graphic analysis and the theoretic approximation provides a flexible yet accurate method of analyzing this parameter.

10,170 THEORETICAL CURRENT MULTIPLICATION OF A CYLINDRICAL HOOK COLLECTOR by D. P. Kennedy (IBM); IBM J. Res. and Dev., Vol. 5, pp. 25-32, Jan. 1961

An analysis of the mechanisms of operation for a current-multiplying hook collector of cylindrical geometry is given. Mathematical equations which establish the minority carrier transport efficiency within a cylindrical hook collector region are presented; both surface and bulk recombination are assumed to be present. Also included in this analysis is the influence, upon current multiplication, of the factors determining minority carrier injection efficiency for a diffused hook emitter junction. Numerical evaluation of appropriate hook collector design equations are presented in graphical form throughout a range of geometrical parameters applicable to many practical situations.

10,171 MAGNETIC FIELDS VARY TRANSISTOR GAIN by R. W. Lade, D. J. Fitzgerald, A. F. Luckas and T. P. Lynch (Marquette U.); Electronics, Vol. 34, pp. 68-70, Feb. 3, 1961

Variation in common-emitter short-circuit current gain with the application of a magnetic field is reported. An uncapped germanium transistor was placed in a strong magnetic field with the rest of the amplifier circuit shielded. With the diffusion current density vector parallel to the magnetic field, voltage



## TRANSISTORS (Cont'd)

gain increased linearly with increasing flux density. Rotation of the transistor  $90^\circ$  with respect to the magnetic field produced an opposite effect. With constant flux density, voltage gain as a function of angular rotation of the field was approximately sinusoidal. A possible cause is the reaction of the base recombination current to the magnetic field. The maximum observed variation in voltage gain was 33 per cent.

10,172 JUNCTION TRANSISTOR TRANSIENT RESPONSE CHARACTERIZATION by J. A. Ekiss and C. D. Simmons (Philco); *Solid State J.*, Vol. 2, pp. 17-24, Jan. 1961

The transient response characteristics of junction transistors are analyzed. Equations for the transition times (delay, rise, storage, and fall times) are presented. The primary emphasis is on the use of these equations to predict switching times accurately. The inherent nonlinearities of the transistor are accounted for by using average values for certain parameters. Prediction of transition times from fundamental parameters when base current is a known function of time is discussed. Experimental evidence is presented to verify the theory. A specification procedure which allows the prediction of the typical and maximum response time of a junction transistor over a wide range of circuit conditions is discussed. The testing procedures necessary to specify the transistor are described.

10,173 AN ANALYSIS AND REPRESENTATION OF JUNCTION TRANSISTORS IN THE SATURATION STATE by Z. Wiencek (Warwick Mfg.); *IRE Trans.*, Vol. ED-8, pp. 87-95, Jan. 1961

Three diffusion processes are used to analyze the transistor behavior in Region III. This leads to a new equivalent circuit representation which is a superposition of the active-state and saturation-state models. Saturation state of the transistor is understood as a state in which both emitter and collector junctions are biased so as to obtain a uniform distribution of the minority carriers in the base. Saturation can be treated separately and can be represented by a new independent model. Transient analysis made on these models, representing saturation and active states, leads to storage and decay phenomena, and storage and decay times agree with those calculated by others.

10,174 ALLOY-DIFFUSED TRANSISTORS by E. Wolfendale (Mullard Res. Labs.); *Electronic Engrg.*, Vol. 33, pp. 88-93, Feb. 1961

The alloy-diffused method of making transistors is described and the reasons for its advantages at VHF are pointed out. The performance of existing alloy-diffused transistors in a number of typical circuits is described and the future range of alloy-diffused transistors is discussed. It is concluded that when the range is fully established it will be possible to replace thermionic tubes for most purposes with the exception of UHF work and power transmitting.

10,175 A COAXIALLY PACKAGED MADT FOR MICROWAVE APPLICATIONS by J. D. McCotter, M. J. Walker (Philco) and M. M. Fortini (Philco Internatl., Switzerland); *IRE Trans.*, Vol. ED-8, pp. 8-12, Jan. 1961

A coaxially packaged transistor capable of delivering greater than 11 db of power gain at 1000 Mc, with a resultant maximum frequency of oscillation of 3500 Mc, is described. This device is a p-n-p micro-alloy diffused-base transistor (MADT). The principal difference between this device and a standard high-

frequency MADT amplifier is the reduction of electrode size and use of a coaxial construction. The parasitic elements,  $r_b'$ , and emitter and collector transition capacities, have very striking effects. Also, the excess phase of alpha at alpha cut-off, as described by Thomas and Moll, can be very large ( $150^\circ$  on this device); for this reason,  $f_T$  rather than  $f_{ca}$  should be used as the figure of merit for graded-base transistors. Because of this excess phase, the value of K (0.85 for homogeneous-base transistors), which is used to relate  $f_T$  to  $f_{ca}$ , can be as low as 0.43 in graded-base transistors of this type.

10,176 IMPURITY CONCENTRATIONS IN THE REGROWN REGION OF In-Ge ALLOYED JUNCTIONS by F. E. Roberts (Mullard Res. Labs.); *Solid-State Electronics*, Vol. 2, pp. 8-13, Jan. 1961

The development of an infrared microscope for routine carrier-density measurements on small semiconducting specimens is described. With its aid, a study of In-Ge and In-Ga-Ge regrown-alloyed regions of a size normally used in transistors has been made. Indium concentrations of  $3-4 \times 10^{18} \text{ cm}^{-3}$  have been found near p-n junctions alloyed at  $615^\circ\text{C}$ , in agreement with the established solidus curve at that temperature, but at  $418^\circ\text{C}$  the results would appear to favor a linear plot of log (distribution coefficient) versus  $1/T^\circ\text{K}$ . In +0.62 atom per cent Ga pellets alloyed at  $618^\circ\text{C}$  yield acceptor concentrations of  $1.4 \times 10^{19} \text{ cm}^{-3}$ . Diffusion lengths have been measured in these regrown regions by photoinjection methods and are found to be of the order of  $5 \mu$ .

10,177 SEMICONDUCTOR DEVICES by C. W. Mueller (RCA); U. S. Pat. 2,967, 344, Issued Jan. 10, 1961

A process for fabricating high frequency, symmetrical, power transistors is described. A junction is produced by diffusing an impurity into the surface of a semiconductor wafer in which a recess has been formed. By removing the diffused layer from all areas except in the recess and at the surface coaxially opposite, a transistor structure is fabricated.

10,178 METHOD OF FORMING SEMICONDUCTOR DEVICES by B. Cornelison and E. A. Wolff, Jr. (Texas Instr.); U. S. Pat. 2,966,720, Issued Jan. 3, 1961

The formation of rectangular, wedge, and conical-shaped transistor structures is discussed. An impurity is diffused into the surface of a semiconductor wafer to form a p-n junction. Selected areas of the original wafer material then are exposed by removal of the diffused layer. Subsequent steps of diffusion of the same impurity and removal of other portions of the diffused layer define the emitter, base, and collector areas. Contacts are fabricated to complete the device.

10,179 TRANSISTOR STRUCTURE AND METHOD OF MAKING THE SAME by R. N. Noyce (Clevite), U. S. Pat. 2,968,750, Issued Jan. 17, 1961

The fabrication of high frequency and field-effect transistors with grids of high conductivity silver-silicon eutectic in the base region or gate is described. An evaporated layer of silver arsenic 2-10 microns thick is alloyed into one surface of a block of p-type silicon to form overlying layers of n-type silicon and silver-silicon eutectic. Another block, of the same type and orientation as the first, has parallel grooves ground into one surface; both blocks are placed together with the grooved surface resting on the eutectic layer. The assembly is then alloyed under pressure and vacuum. When the temperature is below that of the evaporated layer alloying, a continuous n-layer, containing regions of high conductivity eutectic



as grids, will form upon cooling, giving the base of a high frequency transistor. When the temperature is above, both p-regions will unite, enclosing n-regions with eutectic cores, giving gates of a field effect transistor.

10,180 THERMAL EXPANSION FIXTURE FOR SPACING VAPORIZED CONTACTS ON SEMICONDUCTOR DEVICES by D. J. Walsh (Bell Labs.); U.S. Pat. 2,969,296, Issued Jan. 24, 1961

A technique for the mass production of uniformly-spaced parallel contacts on the surface of a semiconductor wafer is described. The wafer is placed in a vacuum chamber between a mask and a base plate made of materials with different thermal coefficients of expansion, and is restrained from moving either laterally or vertically. The wafer, mask and base plate are heated to the temperature necessary for one of the contact metals to wet the semiconductor. The contact metal is then evaporated onto the semiconductor surface. The temperature of the assembly is then lowered to the wetting temperature of the second metal, which is then evaporated. The difference in the thermal contraction between the base plate and the mask results in a relative movement between the mask and the wafer and permits the deposition of parallel contacts. The spacing between the contacts can be varied by proper selection of such parameters as the change of temperature and the contact metals. The method is illustrated by the evaporation of aluminum emitter contacts and gold base contacts during the fabrication of diffused junction transistors.

10,181 METHODS OF PRODUCING STABLE TRANSISTORS by J. J. A. Ploos van Amstel (N. V. Philips); Philips Tech. Rev., Vol. 22, pp. 204-214, 1960/61

The surface state of germanium transistors has a very marked influence on their characteristics, in particular on the current amplification factor. The occupation of the surface by water molecules is shown to be exceptionally important, and is thought to have an optimum value. A favorable water occupation may be maintained in all operating conditions by incorporating in the encapsulant a buffer substance — a stabilizer — which provides the appropriate water-vapor pressure as a function of temperature. Whilst this method produces good transistors with reasonably stable characteristics, better results are obtained with a buffer whose water-vapor pressure is initially too low. After the transistors have been heated for several days at 140°C, they are then found to have very favorable and stable characteristics. The process is described as "surface forming". There are other substances that resemble water in their effect on the surface. Results obtained with one such substance (arsenic) are briefly discussed.

10,182 CIRCUIT MICROELEMENT by H. R. Meisel, L. Schork, A. Pikov and A. Blickev (RCA); U.S. Pat. 2,971,138, Issued Feb. 7, 1961

A technique for sealing semiconductor devices in a package suitable for use in modular circuits is described. The device is inserted into a depression in a ceramic or glass wafer and its electrodes are spot welded to leads protruding through the base of the depression. A potting compound is placed around the device and baked. The package is then hermetically sealed. Electrical contact is made to the device by means of electrodes fired onto the wafer surface. The packaging technique is particularly suited for mass production.

Plastic Casting Machine for Electronic Components — See 10,309

10,183 SEMICONDUCTOR DEVICE by N. C. Jamison (Philips); U.S. Pat. 2,967,984, Issued Jan. 10, 1961

A method of increasing the heat dissipating abilities of transistor and diode structures is described. By the use of metal plates placed adjacent to points of heat generation and by filling the enclosure with an electrically insulating mass into which metallic members have been embedded, a highly conductive thermal path is obtained; electrical isolation between each plate, metallic member, and device electrode is preserved.

10,184 TRANSISTOR STRUCTURE by W. Shockley and R. N. Noyce (Clevite); U.S. Pat. 2,967,985, Issued Jan. 10, 1961

Various methods for the fabrication of high frequency field-effect transistors are described. The basic approach involves the formation of a channel in a diffused or grown layer by etching or machining. Improvements in the device are accomplished by maintaining low capacitance in the junctions between gate to source and drain and a high breakdown voltage in the junction between gate and channel. These ends are attained by producing a low concentration gradient in the junctions between gate to source and drain, and a high concentration gradient between gate and channel, by the techniques of diffusion, out-diffusion, and evaporation and micro-alloying.

Field Effect Transistor Structure — See 10,179

10,185 TEMPERATURE INDEPENDENT TRANSISTOR WITH GRAIN BOUNDARY by H. F. Mataré, B. Reed and O. Weinreich (Sylvania); U.S. Pat. 2,970,229, Issued Jan. 31, 1961

Fabrication of a germanium bicrystal field-effect transistor, operational from 4° to 300°K, is described. The grain boundary of the bicrystal is utilized as a channel with the opposite conductivity type crystal bulk functioning as gate. Graphs of the frequency dependence of input and output currents at 78°K, source to drain voltage current characteristics for varying gate voltage at 4°K, and output-input current versus gate voltage at constant source to drain voltage and room temperature are shown.

## FUNCTIONAL UNITS

10,186 SEMICONDUCTOR SHIFT REGISTER by W. Shockley (Shockley); U.S. Pat. 2,967,952, Issued Jan. 10, 1961

Shift registers that employ n-p-n-p switches as storage elements are described. Formation of the n-p-n-p switch is accomplished by the diffusion of impurities to form layers of alternate p-n-p (or n-p-n) type on a common n (or p) type semiconductor body and the separation of this configuration into n-p-n-p units. Spacing between units is dependent upon the diffusion rate, lifetime, and concentration of injected minority carriers in the common body and the rate cycle of the register. Carriers injected into the common body from a previously triggered unit diffuse through the body to the adjacent unit and forward bias its switching junction; pulsing the unit at this time triggers it into the "on" or "1" condition. This procedure is repeated on the next adjacent unit to transmit the "1" across the register. "Off" or "0" condition is transmitted by not pulsing on the proper interval.



## MAGNETOELECTRIC DEVICES

10,187 HALL EFFECT MAGNET by R. G. Marley (Am. Inst. of Phys.); Am. J. Phys., Vol. 29, pp. 29-31, Jan. 1961

A small electromagnet designed for use with an indium-antimony Hall effect device is described. A coil current of 2.3 amp produces a field of 3 kgauss across a 0.56-cm gap. The field is uniform to within 10 per cent over an area  $1.5 \times 1.5$  cm. Fields high enough for use with a germanium sample are practical.

Hall Effect Magnetic Field Pickup - See 10,299

## RESISTANCE DEVICES

10,188 MARTENETRON MATERIALS FOR USE IN BINARY RESISTANCE DEVICES by P. J. Fopiano (Mfg. Labs.); U. S. Gov. Res. Rep., Vol. 35, p. 95 (A), Jan. 13, 1961  
PB 171 066

Certain metallic systems which exhibit a computer-type hysteresis loop, wherein a discontinuous change in resistance occurs at different temperatures depending on whether the temperature is being increased or decreased, are referred to as martenetron materials. The practicability of employing such materials in nonlinear resistance devices is discussed. The type of solid-state transformation in metallic systems upon which this device is based is known as a martensitic or diffusionless reaction. The selection of a wide range of potential martenetron materials with martensitic reactions has been carried out by surveying the literature. From this list, those systems felt to be of particular interest were investigated. In at least one system (iron-nickel), several compositions have been studied in considerable detail to correlate the effect of composition on the martensitic reaction. In each system, the resistance change, the critical temperature range, and the hysteresis effects (if any) have been determined. With typical high and low temperature materials, the stability after repeated cycling has been measured and metallurgical observations such as microhardness and metallography have been made. The effect of quenching media on switching rate, the heat requirements, and some possible methods of packaging have been investigated.

## PHOTODEVICES

10,189 PHOTOELECTRIC CONVERTER MADE OF POLYCRYSTALLINE SILICON by A. Ya. Gliberman, A. K. Zaitseva, and A. P. Landsman; Soviet Phys.-Solid State, Vol. 2, pp. 1583-1586, Feb. 1961

The operating characteristics of three photoelectric converters made of p-type polycrystalline silicon, with different working surface area and different geometry of surface current conductors, are discussed. Converters composed of separate, small monocrystalline photoelements connected in parallel provided the greatest efficiency of elements, as high as 8 per cent. This construction eliminates harmful effects of intercrystal junctions.

10,190 SPECTRAL RESPONSE OF SOLAR-CELL STRUCTURES by L. M. Terman (Stanford U.); Solid-State Electronics, Vol. 2, pp. 1-7, Jan. 1961

Measurements of the spectral response of silicon solar-cell structures, and of the variation of the response with the depth of the p-n junction are reported. Spectral response is defined as the relative short-circuit current as a function of the wavelength of incident light for equal energy incident upon the cell at all wavelengths. Cells have been made with the junction depths varying from 0.6 to 5.0  $\mu$ , and having both smooth (etched) surfaces and rough (lapped) surfaces. Response curves from these cells are presented. These curves indicate that in order to increase the relative short-wavelength response ( $\lambda < 0.75 \mu$ ) the junction should be made closer to the surface, while in order to increase the relative long-wavelength response ( $\lambda > 0.75 \mu$ ) the junction must be made comparatively far below the surface. The effect of having a lapped surface on the cell is to reduce the lifetime near the surface, thus reducing the response to short wavelengths of incident light. A simple theoretical model which appears adequately to describe the mechanism involved in determining the shape of the response curves is presented.

10,191 CONSIDERATIONS ON THE SOLAR CELL by D. A. Kleinman (Bell Labs.); Bell Sys. Tech. J., Vol. XL, pp. 85-114, Jan. 1961

The collection efficiency in solar cells is treated by a new method in which all the effects of the solar spectrum and the absorption curve are contained in a single function readily obtained by numerical integration. The method is illustrated by a detailed study of the effects of surface recombination, body recombination and junction depth in silicon cells. The method is also generalized to include built-in electric fields. Calculations are given for silicon. Sufficiently strong fields to improve the collection efficiency markedly can be produced in some compound semiconductors from a gradient in the energy gap. The dependence of the collection efficiency on the absorption curve of the semiconductor is discussed. It is shown that silicon has a very favorable absorption curve in comparison with GaAs or InP. Finally, the minority carrier collection in a two-junction cell is treated and calculations are presented for silicon. It is concluded that this structure may be important for cells with high energy gaps and short lifetimes.

10,192 INVESTIGATION OF INTEGRALLY COMPOSED VARIABLE ENERGY GAP PHOTOVOLTAIC SOLAR ENERGY CONVERTER by L. E. Stone, J. E. Powderly, and W. E. Medcalf (Eagle-Picher Res. Labs.); U. S. Gov. Res. Rep., Vol. 35, p. 211 (A), Feb. 10, 1961 PB 149 705

An investigation of integrally composed multiple energy gap solar cells is described. The objective was to contrast the efficiency and other characteristics of such cells with the characteristics of conventional single energy gap cells. The multiple band gap cell under study was a composite solar cell made up of gallium phosphide and gallium arsenide.

10,193 MODULATION OF COHERENT LIGHT by J. E. Rosenthal (Bramley); Bull. Am. Phys. Soc., Ser. II, Vol. 6, p. 68 (A), Feb. 1, 1961

To use an optical maser effectively as a means of transmitting information, the light must be probed time sequentially at every point of information in a wave-front plane. Time sequential modulation of different areas in the cross section of a coherent light beam by maser modulation seems impractical. Ideally, rates of transmission should be comparable to the number of photons per second emitted by the maser. Modulation of the transmitting property of a light valve irradiated by coherent light could partially exploit the possibility of using the spatial



## PHOTODEVICES (Cont'd)

tribution of information. A light valve which uses carrier density modulation of light passing through an epitaxial semiconductor sheet was discussed. Speed of presentation of information depends among other factors on position of semiconductor absorption edge and free carrier lifetime. A modulated electron beam injects the carriers into the semiconductor. With this mode of operation, rates of presentation of  $10^{10}$  bits and higher should be realizable. Although readily available semiconductor sheets might serve this purpose in conjunction with a Hughes type optical maser, better results would be obtained if the characteristics of the two components could be matched.

## THERMAL DEVICES

10,194 THERMOELECTRIC BEHAVIOR OF P-N JUNCTIONS by M. Cutler (Genl. Dynamics); J. Appl. Phys., Vol. 32, pp. 222-227, Feb. 1961

Equations for the flow of carriers and electronic heat which occurs when a temperature drop as well as an applied potential exists across a p-n junction are derived on the basis of an emission model. The application of the equations is discussed for small-signal situations, where the Onsager relation is obeyed, as well as for large-signal situations. In particular, the efficiency of p-n junctions for thermoelectric conversion is compared with that of homogeneous semiconductors and thermionic diodes.

10,195 SELECTION OF MELTING POINTS AND ENERGY GAPS FOR OPTIMIZED MATERIALS PERFORMANCE by N. Chasmar, W. Tantraporn, and W. J. van der Grinten (GE); 61 Symp. Thermoelectric Energy Conversion

Some criteria for finding the best thermoelectric material at a given operating temperature were discussed. It was recommended that thermoelectric materials be selected for operation in the vicinity of their melting points and that, through solid solution alloying preferably accompanied by disordered mass scattering in a sub-lattice, their energy gap be adjusted to about  $4kT$  at this temperature. This relationship depends somewhat on mobility ratios. Chasmar and Stratton [see abst. 4393] arrive at substantially higher recommended  $kT$  values. Theoretical investigations reported in the literature predict a strong temperature dependence of phonon conductivity. An increase proportional to the square of the melting temperature is indicated for some homologous series.

10,196 TRANSIENT RESPONSE OF A THERMOCOUPLE CIRCUIT UNDER STEADY CURRENTS by A. D. Reich and J. R. Madigan (Borg-Warner); J. Appl. Phys., Vol. 32, pp. 294-301, Feb. 1961

Heat transfer calculations for a thermocouple circuit functioning as a Peltier cooler are presented. The calculations depend upon the exact solution of a one-dimensional time-dependent heat equation. It is shown that for an unloaded couple the temperature at the cold junction will be less than or equal to the reference junction temperature only for currents in the range from zero to twice the optimum current (i.e., the current that produces the minimum cold junction temperature). The temperature at the cold junction has been investigated as a function of time, and shown to approach the steady-state values appropriate to any particular multiple of the optimum current at

that point with increasing time. It has been shown that one cannot produce a transient thermal spike at the cold junction which is greater in magnitude than the steady-state temperature for the optimum current by initially applying currents greater than the optimum. The possibility of achieving such thermal spikes by superposing a current pulse upon the steady-state current is discussed. The possibility of using the transient response of thermocouple junctions for the measurement of thermal conductivity is examined.

Bismuth Telluride Thermocouples - See 10,030

10,197 TEST AND COMPARISONS OF CARBON AND GERMANIUM THERMOMETERS by P. Lindenfeld (Rutgers U.); Rev. Sci. Instr., Vol. 32, pp. 9-11, Jan. 1961

Calibration and testing of two encapsulated germanium thermometers between  $1.4^{\circ}$  and  $4.2^{\circ}$  K are described. Within the precision of the measurements ( $\pm 0.4$  millidegree) no change in their calibration was found after cycling to room temperature or after temporary removal from the measuring apparatus. In this respect, the germanium thermometers were considerably better than carbon thermometers. For comparison a carbon thermometer was encapsulated and found to undergo unpredictable changes corresponding to several millidegrees under similar circumstances.

## FERRITE DEVICES

10,198 WIDE-BAND RESONANCE ISOLATOR by W. W. Anderson and M. E. Hines (Bell Labs.); IRE Trans., Vol. MTT-9, pp. 63-67, Jan. 1961

A parallel-plate transmission line loaded with capacitors or high dielectric constant material along a narrow strip has a circularly polarized RF magnetic field everywhere external to the loading over a very broad band. The magnetic resonance line of a narrow linewidth ferrite has been inhomogeneously broadened by a very inhomogeneous magnetic field to provide resonance absorption over a wide frequency range. A prototype structure has given better than 15 db per inch attenuation in the reverse direction over a bandwidth from 1.5 kMc to 6.0 kMc. The forward loss caused by the ferrite is about 0.2 db to 0.4 db over this range of operation.

10,199 STRIPLINE Y-CIRCULATORS FOR THE 100 TO 400 MC REGION by G. V. Buehler and A. F. Eikenberg (Electronic Commun.); Proc. IRE., Vol. 49, pp. 518-519 (L), Feb. 1961

Stripline Y-circulators which operate in the frequency region below 400 Mc are described. A low  $M_s$ , MnMg aluminate ferrite is used in the form of circular disks (0.405 in thick). The loss and isolation characteristics are symmetrical, with respect to the center frequency, for constant magnetic fields; asymmetrical for variable magnetic fields. Saturation of the ferrite disk is necessary for low insertion loss. The device is operated close to resonance. A frequency range of 100 to 1000 Mc with maximum isolation of 25 to 40 db at a minimum insertion loss of 0.6 db has been obtained. The bandwidth decreases rapidly with increasing disk diameter necessary for very low frequency operation.

10,200 RESEARCH ON MAGNETIC ROD STORAGE AND SWITCHING DEVICE by A. J. Kolk (NCR); U.S. Gov. Res.



## FERRITE DEVICES (Cont'd)

Rep., Vol. 35, p. 207 (A), Feb. 10, 1961 PB 152 520

The results of a study of the magnetic properties of thin film, iron-nickel alloys electrode-positing in a ROD configuration are presented. These properties were found to be critically influenced by the physical condition of the conducting substrate surface. Silvered-glass and beryllium-copper substrates were subjected to intensive investigation. The effects of varying other plating parameters such as current density, pH, bath composition, temperature, organic additives, plating time, and the presence of an axial magnetic field were also studied. Electron micrographs were made of the substrate surface and the plate at different plate thicknesses. An attempt was made to correlate residual stress measurements with the properties of the plate. Preferred orientation in the plate was investigated by means of x-ray diffraction techniques. Finally, a series of experimental switching curves were determined and a mechanism for the switching phenomena was proposed.

Irreversible Domain Patterns in Thin Magnetic Films - See 10,279

10,201 BACKWARD WAVES IN LONGITUDINALLY MAGNETIZED FERRITE RODS by A. W. Trivelpiece, A. Ignatius, and P. C. Holscher (Lab. voor Elek. Tech. Hogeschool, Netherlands); *J. Appl. Phys.*, Vol. 32, pp. 259-267, Feb. 1961

A quasi-static approximation is used to investigate the backward waves that propagate along a longitudinally magnetized ferrite rod. These waves propagate in the frequency range where the permeability of the ferrite is negative and can have a phase velocity much smaller than the velocity of light. The quasi-static approximation is shown to be valid whenever the free-space wavelength is greater than the circumference of the ferrite rod. Traveling-wave interaction of a drifting electron stream with these backward waves is considered, and a start-oscillation length of 1 in. at 4000 Mc is shown to be theoretically possible for a 600-v, 0.4-ma electron beam. Experimental verification of these waves is provided by measuring the phase velocity and signal strength along a longitudinally magnetized ferrite rod that completely fills a waveguide. Phase velocities as small as one one-hundredth of the velocity of light are measured.

## MASERS AND LASERS

10,202 MASER SYSTEM NORMALIZED POPULATION DISTRIBUTION CALCULATED BY METHOD OF PARTIAL DISTRIBUTION by J. D. Keating, L. E. Follis, and W. A. Barker (McDonnell); *Bull. Am. Phys. Soc.*, Vol. 6, Ser. II, p. 68 (A), Feb. 1, 1961

A method of solution for the normalized population distribution and differences of a multilevel maser system was described. In this method, the total normalized population of a given level  $n_i$  is considered to be the sum of a number of competing transition processes, each of which results in a partial population distribution. The relative contribution to the total population of each of the competing processes is determined by a weighting factor,  $f_i$ , which is a function of the thermal and radiative transition probabilities. The viewpoint is analogous to that of a chemical system of  $r$  competing chemical reactions, each of which reacts to give a partial distribution of  $\beta$  end products,

with each of the reactions contributing  $f_i$  ( $i = 1, 2, \dots, r$ ) mole fractions to the total of each of the  $\beta$  end products. The normalized population distributions of a three-level system and a four-level system calculated by this method have been determined to be identically equal to the distributions normally found by solution of the rate equations. The four-level system was discussed in detail.

10,203 CROSS RELAXATION AND CONCENTRATION EFFECTS IN RUBY by R. W. Roberts and H. D. Tenney (Melabs) and J. H. Burgess (Stanford U.); *Phys. Rev.*, Vol. 121, pp. 997-1000, Feb. 15, 1961

Cross relaxation effects in ruby maser crystals are treated by introduction of a cross relaxation probability in the rate equations. Detailed solutions have been obtained for several specific processes and compared to recent experiments. It is shown that cross relaxation can improve maser performance even in the absence of impurity doping. Pulse experiments at 0.06 and 0.14 per cent chromium ion concentrations in a ruby traveling wave maser are interpreted in terms of a five-spin process in addition to a four-spin process.

10,204 MONOCHROMATICITY AND DIRECTIONALITY OF COHERENT LIGHT FROM RUBY by C. G. B. Garrett, W. L. Bond, and W. K. Kaiser (Bell Labs.); *Bull. Am. Phys. Soc.*, Ser. II, Vol. 6, p. 68 (A), Feb. 1, 1961

An investigation of the light produced by a ruby rod operated as a pulsed optical maser with a 10mm Fabry-Perot etalon was described. The coherent light was found to emerge from the end of the rod in an extremely narrow cone. The width of the Fabry-Perot fringes within this cone indicates a line sharpening of nearly two orders of magnitude. Within the resolving power of the etalon ( $0.05 \text{ cm}^{-1}$ ), all of the light within the cone possesses the same wavelength and the same line width. Furthermore, in most cases, the wavelength is maintained for the full duration of the phenomenon ( $5 \times 10^{-4} \text{ sec}$ ) in spite of the fact that the light is emitted in many short bursts, each about  $10^{-6} \text{ sec}$  long, rather than continuously. In some experiments, a mosaic structure, having a spacing of the order of  $1/100^\circ$ , also is seen; this phenomenon is not due to gross interference effects but is probably associated with the complex spatial configuration of the coherent field within the ruby.

10,205 COHERENCE EXPERIMENTS WITH A PULSED RUBY OPTICAL MASER by D. F. Nelson, R. J. Collins, and A. L. Schawlow (Bell Labs.); *Bull. Am. Phys. Soc.*, Ser. II, Vol. 6, p. 68 (A), Feb. 1, 1961

Spatial coherence of a light beam can be investigated by causing different parts of a wave front to interfere, e.g., Young's experiment. By taking this approach the coherence of the emission from a pulsed ruby optical maser was measured using two slit interference patterns. The maser used in these experiments was similar to that reported earlier except for the inclusion of two slit shaped openings in the silver end coatings. The interference fringes obtained had the expected angular separation and intensity ratios. This and other experiments lead to the conclusion that the maser light is coherent across the end of the rod for distances of hundreds of wavelengths. The fringes disappear below the maser threshold since the normal fluorescence cannot produce interference fringes within this geometry. Structure in the maser emission perpendicular to the main pattern has been observed. The amount of this structure increases as the excitation is increased above the maser threshold. A discussion of the relation of this structure to the crystal perfection and the relaxation oscillations was given.



## MASERS AND LASERS (Cont'd)

10,206 PROPOSED FIBER CAVITIES FOR OPTICAL MASERS by E. Snitzer (Am. Opt.); J. Appl. Phys., Vol. 32, pp. 36-39, Jan. 1961

The use of dielectric waveguides in the form of small fibers as the mode selector in optical masers is considered. The fibers consist of a core of index of refraction  $n_1$  which contains the laser material, surrounded by a cladding of lower index  $n_2$ . A comparison is made with the Fabry-Perot interferometer used as a cavity. The principal advantages of the fiber for maser applications are the mode selection and the stronger mode coupling. It is shown that for core diameters just small enough to support only the two  $HE_{11}$  modes, the fraction of spontaneous emissions into the waveguide modes is given approximately by  $4(n_1 - n_2)/(n_1 + n_2)$ . This could make maser action possible at much lower power levels. The major disadvantage is the difficulty of pumping into the small volume of the fiber. Schemes to overcome this difficulty are discussed.

Effective Use of Lasers for Information Transmission - See 10,193

10,207 SEESAW MASER OPERATION by P. A. Forrester and J. B. Mims (Bell Labs.); J. Appl. Phys., Vol. 32, pp. 317-320, Feb. 1961

Use of cross relaxation between adjacent intervals to secure an advantage in maser operation comparable to that obtained by "push-pull" pumping is described. Equations for the rate of change of populations in a scheme of four levels (A, B, C, D) when AC is pumped and cross relaxation takes place between C, CD are formulated, and the steady-state condition corresponding to various assumptions regarding lattice relaxation times is discussed. In an experimental investigation of maser operation based on this scheme and using ruby as the active material, an inversion of 0.9:1 was obtained at a signal frequency of 14.5 kMc when pumping at 24.5 kMc.

10,208 MASER OPERATION AT SIGNAL FREQUENCIES HIGHER THAN PUMP FREQUENCY by F. R. Arams (Cutler-Hammer); IRE Trans., Vol. MTT-9, pp. 68-72, Jan. 1961

Methods using harmonic spin coupling for operating solid-state masers with signal frequencies higher than the pump frequency are discussed. Expressions for the population inversion ratios are presented, and the maximum signal-to-pump-frequency ratios are calculated. Experimental data is presented on a ruby maser which is operated using the symmetrical method. Amplification was obtained at signal frequencies from 10,320 to 10,740 Mc, using pump frequencies ranging from 9580 to 970 Mc. An experiment in which maser operation is obtained simultaneously at two frequencies is described.

Maser Radiometers - See 10,257 and 10,258

## OTHER SOLID STATE DEVICES

10,209 THE A-C PROPERTIES OF TANTALUM SOLID ELECTROLYTIC CAPACITORS by D. A. McLean (Bell Labs.); Electrochem. Soc., Vol. 108, pp. 48-56, Jan. 1961

Two basic elements in the dissipation factor of tantalum

solid electrolytic capacitors are  $\tan \delta'$ , the substantially frequency independent dissipation factor of the tantalum oxide, and  $R_2$ , the lumped effective resistance of  $MnO_2$  or other series constituents. These elements can be separated and evaluated from measurements at two frequencies. Use of such evaluation in applied research is illustrated. The value of  $R_2$  is related analytically to the resistivity of the  $MnO_2$  network and the dimensions of an idealized right cylindrical porous capacitor structure. Variation of capacitance with frequency for a large number of commercial capacitors is found to be related to  $\tan \delta'$  in a way proposed in the literature for anodic oxides.

10,210 TRANSIENT ANALYSIS OF CRYOTRON NETWORKS BY COMPUTER SIMULATION by M. K. Haynes (IBM); Proc. IRE, Vol. 49, pp. 245-257, Jan. 1961

A general method for transient analysis of complicated nonlinear dynamical systems by use of a digital computer programmed to perform tensor transformations and numerical integration is derived. Tensor methods, adapted from Kron's techniques, are used for converting circuit data into a form for transient simulation by numerical integration. An IBM 704 program has been written for simulation of cryotron networks. This simulator has been used to study switching speeds of cross-latched cryotron flip-flops; five-stage, free-running, ring circuits; and a three-bit, self-timing, self-checking, binary, parallel adder. The adder circuit contains 233 circuit elements, including 93 cryotrons arranged in 55 meshes. Results of these studies are included.

10,211 TEN-KILOGAUSS SUPERCONDUCTING SOLENOID; RESISTIVE TRANSITION IN SUPERCONDUCTING NIOBIUM by S. H. Autler (Lincoln Lab.) and L. J. Donadieu (MIT); Bull. Am. Phys. Soc., Ser. II, Vol. 6, p. 64 (A), Feb. 1, 1961

The maximum field strength obtained with a superconducting niobium solenoid has been extended to 9.8 gauss at 1.5°K and 7.1 kgauss at 4.2°K. The solenoid consists of a Teflon form holding two windings in parallel of 0.004 in-diam unannealed niobium wire. The resistance transitions of short samples of niobium wire in various states of strain were studied as a function of the current in the wire, applied transverse magnetic field strength, and temperature. The field strength  $H$  and current  $I$  at which a barely observable voltage appeared across the samples obey relationships of the form  $H = H_0 - A \log I$  over more than 5 decades of current. No evidence of a true resistance discontinuity was seen. Implications for the design of superconducting solenoids and the possibility of generating fields somewhat higher than 10 kgauss with niobium were discussed.

10,212 SEMICONDUCTOR STRAIN GAGES OFFER HIGH SENSITIVITY by R. E. Talmo (Micro Systems); Electronics, Vol. 34, pp. 43-45, Feb. 24, 1961

Semiconductor strain gages with sensitivities 10-100 times greater than metallic devices and with zero and sensitivity shift compensation are described. Since it is a single crystal device, the semiconductor strain gage exhibits a nearly ideal stress-strain characteristic with no plastic deformation below 900°F and an absence of hysteresis. Maximum strain levels of 3000-6000 microinch per inch are possible and strain levels of a fraction of a microinch per inch can be resolved. The gages can be used in both a-c and d-c excited circuits due to their resistive nature. Temperature compensation and increased output are obtained by use of a bridge configuration which provides a first-order correction to zero shift. Sensitivity shift with temperature is corrected by a thermistor network in either the input or output leads.



## OTHER SOLID STATE DEVICES (Cont'd)

10,213 PIEZOELECTRIC PROBE FOR PLASMA RESEARCH by M. O. Stern and E. N. Dacus (Genl. Dynamics); Rev. Sci. Instr., Vol. 32, p. 140-143, Jan. 1961

A piezoelectric probe which has been devised for use in plasma work, where one wishes to measure phenomena of short time duration (microseconds) giving rise to moderately small pressures (fractions of an atmosphere) is described. Some of the response characteristics of such a probe and a method for its calibration are also presented.

10,214 QUARTZ AT-TYPE FILTER CRYSTALS FOR THE FREQUENCY RANGE 0.7 TO 60 MC by R. Bechmann (USASRD); Proc. IRE, Vol. 49, pp. 523-524 (L), Feb. 1961

Design data leading to suppression of unwanted modes to at least 40 db below the main mode for AT-type crystals in the frequency range 0.7-60Mc are given. The behavior of unwanted modes is determined by the plate diameter and thickness and the electrode diameter. For small diameter-thickness ratios, the unwanted modes can be suppressed by adequate beveling of the plate edges. Small changes in the radius of the bevel change the crystal performance. Design equations and data tables are given and the motional parameters are presented.

10,215 CONTINUOUSLY-VARIABLE GLASS DELAY LINE by H. A. Brouneus and W. H. Jenkins (Corning Glass); Electronics, Vol. 34, pp. 86-87, Jan. 13, 1961

A continuously variable glass delay line is described. When glass is stressed, it becomes birefringent; i.e., it presents two different refractive indices to light polarized parallel to and perpendicular to the direction of stress. The magnitude of this difference varies with the stress, and so produces a variation in phase retardation between the two mutually perpendicular components into which plane polarized light transmitted through the glass may be resolved. A traveling acoustic wave generated by a recently developed large area ferroelectric ceramic transducer introduces along the length of a glass bar a stress wave which produces birefringent effects throughout the bar. Polarized light is introduced to the axis of the bar perpendicular to the axis of piezoelectric signal input, and the variations of output light corresponding to variations in input signal are passed through an optical analyzer which in turn passes light to a photomultiplier where the delayed input signal is observed. Possibilities for commutation functions exist.

## BASIC SOLID STATE DEVICE CIRCUITS

### GENERAL

10,216 SYNTHESIS OF N-PORT ACTIVE RC NETWORKS by I. W. Sandberg (Bell Labs.); Bell Sys. Tech. J., Vol. XL, pp. 329-347, Jan. 1961

The following basic theorem concerning active RC networks is

proved: An arbitrary  $N \times N$  matrix of real rational functions in the complex-frequency variable ( $s$ ) can be realized as the short-circuit admittance matrix of a transformerless active RC  $N$ -port network containing  $N$  real-coefficient controlled sources, and (b) cannot, in general, be realized as the short-circuit admittance matrix of an active RC network containing less than  $N$  controlled sources.

Transient Analysis of Cryotron Networks by Computer Simulation - See 10,210

10,217 CIRCUIT CONSIDERATIONS RELATING TO MICROELECTRONICS by J. J. Suran (GE); Proc. IRE, Vol. 49, pp. 420-426, Feb. 1961

Five basic problems associated with microscale circuits are considered: power dissipation, thermal generation and its effects on component packing density, compatibility, adjustability and reliability. Power dissipation and its relation to circuit functions is discussed in detail and specific circuit problems are used as examples of the principles. Furthermore, it is shown that the power dissipation problems are fundamental and relate generally to all classes of electronic components. Power dissipation and heat generation are then related to packing density to determine the physical limitations of microelectronic fabrication.

10,218 RECENT ADVANCES IN MICROMINIATURIZATION, RELIABLE COMPONENTS AND COOLING TECHNIQUES by G. W. A. Dummer (RRE); Solid-State Electronics, Vol. 2, pp. 18-34, Jan. 1961

Recent work on electronic components and constructional techniques for equipments, including microminiaturization and cooling methods, is described. In microminiaturization techniques maximum attention is given to the solid-circuit approach with microcircuit on 2D being developed to obtain experience with film components. Circuits using all-silicon components have been constructed using transistor fabrication techniques. Most of the work on flat-plate or 2D circuits has been done on 0.6in square glass substrates, and resistors of evaporated nickel chromium using "in situ" copper masks also evaporated have been successfully made and evaluated. Evaporation of dielectric materials for capacitors has not been so successful and a comprehensive programme of research into the stresses and strains developed in thin films, measurement techniques for accurate deposition and the study of initial stages in the nucleation and growth of thin films using radioactive tracer techniques, are all being carried out. Films have been made inside an electron microscope of the actual growth and nucleation processes of thin films.

Encapsulated Circuit Modules - See 10,310

Thin Film Microcircuits - See 10,311

### AMPLIFIERS

10,219 AGC OF SILICON TETRODES by C. Tatom (Texas Instr.); Solid State J., Vol. 2, pp. 30-36, Feb. 1961

Automatic gain control of silicon tetrodes is discussed. The silicon tetrode transistor exhibits excellent AGC characteristics in comparison with triodes. For IF applications in particu-



## AMPLIFIERS (Cont'd)

er, bandwidth and center-frequency changes can be held to a minimum by applying AGC voltages to both the emitter and base-two. The silicon 2N715 and 2N716 are both well suited for detector applications for AGC of tetrodes. A power detector circuit which gives excellent results as a combined wide-range signal and AGC detector, so long as moderate modulation levels are encountered, is discussed.

Direct-Coupled Transistor Amplifier - See 10,236

10,220 NON-LINEAR DISTORTION OF TRANSISTORIZED AMPLIFIERS by H. H. van Abbe and G. C. van Slagmaat (Phillips Semicon. Dev. Lab.); Electronic Applications, Vol. 1, pp. 159-168, 1959-1960

It is shown that the distortion in a transistor amplifier arises mainly from three sources, the second harmonic components of which are not always in phase. It is possible to minimize the distortion by suitable choice of the source resistance and/or by applying non-linear negative feedback.

10,221 A CIRCUIT FOR THE COMPENSATION OF THE VOLTAGE DRIFT IN THE INPUT STAGE OF A DIRECT-COUPLED TRANSISTOR DC AMPLIFIER [in German] by U. Melken, (Tech. Hochschule, München); Nachrichtentech. Z., Vol. 14, pp. 32-36, Jan. 1961

For all germanium transistors the base-emitter voltage varies by approximately  $-2.3 \text{ mV}/^{\circ}\text{C}$  when the collector current and voltage are kept constant. An equation is derived and difference measurements on 10 type OC350 transistors have indicated that the voltage variations follow this equation with a maximum error of approximately  $20 \text{ } \mu\text{V}/^{\circ}\text{C}$ . An amplifier circuit in which the temperature drift of the base-emitter voltage is compensated to almost the theoretical limit determined by scatter values between samples is described.

Diffused Transistors for VHF - See 10,174

10,222 SELECTIVE RC AMPLIFIER USING TRANSISTORS by J. Hutchins (A.E.I.); Electronic Engrg., Vol. 33, pp. 84-87, Dec. 1961

The use of phase-shift networks in transistor circuits is discussed. The dual of the Wien bridge arm is used to form an oscillator and a selective amplifier. The selective amplifier described has continuously variable selectivity and tuning while the gain remains constant.

10,223 A TRANSISTORIZED PHASE SPLITTER STAGE [in German] by M. Stanek; Slaboproudy Obzor, Vol. 22, pp. 86-87, Feb. 1961

A transistorized audio frequency amplifier with the load in both collector and emitter circuits is analyzed. Its practical application as a driver stage for a push-pull amplifier is discussed and the circuit of a preamplifier and a push-pull stage with complementary transistors is given for the sake of comparison.

10,224 A LOW-NOISE X-BAND PARAMETRIC AMPLIFIER USING A SILICON MESA DIODE by R. D. Weglein and F. J. Wywell (Hughes Aircraft); IRE Trans., Vol. MTT-9, pp. 39-41, Jan. 1961

The development of silicon mesa variable-capacitance diodes

is described and their potential for achieving low-noise amplification in the high microwave frequency range is evaluated. Cutoff frequencies of about 70 kMc at zero-bias voltage (corresponding to 140 kMc at maximum reverse bias voltage) with a total permissible voltage swing in excess of 5 volts have been obtained. A versatile degenerate X-band parametric amplifier was developed which, when used in conjunction with these silicon mesa diodes, achieved a radiometer noise temperature of  $130^{\circ}\text{K}$  at 8.5 kMc with a 50-Mc bandwidth at 17 db gain. The measured performance of the diode (figure of merit) is compared with the first-order theory in an operating radar system. The over-all performance of the amplifier improved the observed system sensitivity by 6 db.

10,225 PARAMETRIC AMPLIFIER USING A SILVER BONDED DIODE by S. Kita, T. Okajima, and M. Chung (Nippon Tel. and Tel.); IRE Trans., Vol. ED-8, No. 2, pp. 105-109, Mar. 1961

A bonded diode composed of a silver-gallium whisker and an N-type germanium wafer which is suitable for use in a parametric amplifier is described. The cutoff frequency of the diode is higher than 150 kMc. A parametric amplifier was made using these diodes at 6 kMc and 11 kMc, and a stable gain of more than 20 db was obtained. The noise figures were approximately 5 db and 6.5 db at 6 kMc, respectively. [see also abst. 10,156].

GaAs Point-Contact Diodes for Microwave Parametric Amplifiers - See 10,155

10,226 CAPACITANCE DEFINITIONS FOR PARAMETRIC OPERATION by H. Heffner (ONR); IRE Trans., Vol. MTT-9, pp. 98-99 (L), Jan. 1961

The definitions of nonlinear time-varying capacitance used by Heffner and Wade [see abst. 2616] and by Rowe [see abst. 2245] are discussed. It is shown that in the definition of Heffner and Wade the small signal ratio of the a-c capacitance at the signal and idling frequencies to the static capacitance observed when only the pump and bias are applied is equal to or less than 2. If both are measured at signal or idling frequencies there is no limit to the ratio of the capacitances. The two definitions are shown to be consistent.

10,227 A HIGH-PERFORMANCE X-BAND PARAMETRIC AMPLIFIER by B. T. Vincent (Texas Instr.); Proc. IRE, Vol. 49, pp. 511-512 (L), Feb. 1961

A degenerate X-band parametric amplifier with a gain-bandwidth product of 10,000 Mc and a noise figure as low as 0.77 dsb is described. The amplifier employs a diffused-junction gallium-arsenide diode operated near its series resonant frequency. The self-resonant frequency of the diode is the principal resonant circuit in the amplifier. The center of the amplifier passband for measurements was 8.62 Gc. Larger bandwidths were obtained but it was not possible to restrict ripple to 3 db. The gain-bandwidth products are based on the double-channel gain. The single-channel gain is 3 db less.

10,228 STAGGERED OPERATION OF DOUBLY RESONANT PARAMETRIC AMPLIFIERS by S. Hamada and H. Mukai; Rev. Electr. Comm. Labor., Vol. NTT-9, Nos. 1-2, pp. 22-25, Jan.-Feb. 1961

Use of doubly-resonant variable-capacitance parametric amplifiers in the 6 Gc band to obtain a broad bandwidth is described. A double-resonant amplifier has been achieved by inserting a resonant stub into a waveguide cavity. The

## AMPLIFIERS (Cont'd)

experimental results, especially the improvement of bandwidth characteristics realized by adjusting the phase difference between the pumps of two parametric amplifiers connected in cascade, are reported. A bandwidth of 55 Mc has been obtained with a gain of 29 db.

10,229 A STUDY OF THE OPTIMUM DESIGN OF WIDE-BAND PARAMETRIC AMPLIFIERS AND UP-CONVERTERS by G. L. Matthaei (Stanford Res. Inst.); IRE Trans., Vol. MTT-9, pp. 23-38, Jan. 1961

Single-diode parametric amplifiers or up-converters using multiple-resonator filters as coupling networks can be made to have considerably larger bandwidths than corresponding amplifiers having single-resonator coupling circuits. Data are presented from which the coupling-filter bandwidths required for given coupling network complexity, diode parameters, and gain can be determined for both parametric amplifiers and up-converters. In the cases of nondegenerate parametric amplifiers and up-converters, the fact that the diode must be brought to resonance at more than one frequency has an added limiting effect on bandwidth. Some trial amplifier designs are shown, and important considerations in the synthesis of the coupling filters are noted. It is seen that for the case of upper-sideband up-converters, if a filter having  $n$  resonators is used in both the input and upper-sideband circuits, then the over-all response can be made to correspond to that of a filter with  $2n$  resonators. The gain characteristics of the trial amplifier designs as determined with a digital computer are included. Computed responses ranging in bandwidth from 9 to 27 per cent are obtained for multi-resonator designs having  $C_1/C_0 = 0.25$ .

Four-Frequency Parametric Amplifiers - See 10,248

10,230 DESIGNING TUNNEL DIODE RF AMPLIFIERS by E. D. Long and C. P. Womack (Wilcox Elect.); Electronics, Vol. 34, pp. 120-123, Feb. 17, 1961

Use of a germanium tunnel diode as a low-noise, low-level, RF amplifier is described. The amplifier is used in a receiver front end with a center frequency of 330 Mc,  $\pm 0.5\%$ , in conjunction with a maximally flat bandpass filter. Design equations for the tunnel diode amplifier are presented and development of the filter is described. To prevent the tunnel diode from operating as a switch, the bias is set by a constant voltage source. The minimum theoretical noise figure is 2.7. The amplifier is fabricated on a through stripline with the gain controlled by a variable capacitor from anode to ground. A stable insertion gain of 25 db has been obtained. Photoetch techniques are used for both the stripline filter and the tunnel diode amplifier.

10,231 A TECHNIQUE FOR CASCADING TUNNEL DIODE AMPLIFIERS by C. O. Harbourt (Syracuse U.); Proc. IRE, Vol. 49, pp. 373-374 (L), Jan. 1961

An analysis of the possibility of cascading amplifier stages using non-ideal negative resistance devices is presented. The analytical technique of separating the bias and signal characteristics leads to the conclusion that the cascading scheme proposed by P. M. Chirlian ("A Technique for Cascading Tunnel Diode Amplifiers", Proc. IRE, Vol. 48, p. 1156, June 1960) cannot be used for tunnel-diode-like negative resistance devices except possibly at high frequencies. A more general approach in which bias and signal considerations are not separated is also shown to yield no useful answer to the stability question.

Transistor-Magnetic Core Amplifier for Logic Circuits - See 10,268

Miniature Low-Noise Preamplifier - See 10,312

10,232 POWER AMPLIFIER DESIGN NOMOGRAPH by J. S. MacDougal (Raytheon); Solid State J., Vol. 2, pp. 32-34, Jan. 1961

Three examples showing the use of a nomograph in solving the power output equations are presented. Saturation resistance definitions are discussed.

## OSCILLATORS

10,233 A WIDE BAND VOLTAGE CONTROLLED OSCILLATOR by M. A. Weston (SRDE); Electronic Engrg., Vol. 33, pp. 2-5, Jan. 1961

A method of obtaining electronic tuning of an oscillator over a wide band of frequencies in the megacycle range is described. The circuit is essentially that of an LC oscillator, the frequency of which is varied by electronically switching a number of fixed capacitors across the tuning inductance. The various factors affecting oscillator linearity and stability are discussed, and the circuit diagram of an oscillator covering the range 1.5 Mc/s to 3.0 Mc/s with a maximum non-linearity of 0.5 per cent is given.

10,234 STARTING CIRCUIT by E. P. Donnelly, Jr. (U.S.A.); U.S. Pat. 2,970,279, Issued Jan. 31, 1961

A technique for providing the energy surge required to initiate oscillations in a transistor oscillator which employs an energy source with a slowly rising voltage characteristic is described. The application of energy to the oscillator is prevented by a shunt circuit connected across the input terminals of the oscillator until the slowly-rising energy source is at the value required to initiate oscillations. In one example the shunt consists of a resistor and a fuse. When the current flow through the shunt reaches the required value the fuse melts and energy is applied to the oscillator.

10,235 A LIGHT-CONTROLLED AUDIO-TONE GENERATOR by K. Holford (Mullard Res. Labs.); Mullard Tech. Commun., Vol. 5, pp. 231-234, Jan. 1961

A light-controlled transistor oscillator circuit developed to permit blind operators to monitor the lamp indicators on telephone PABX switchboards is described. The transformer-coupled 800 cps oscillator is light-controlled by a cadmium sulfide cell included in the bias chain. The oscillator responds to both steady light and light flashing at 2.5 cps and feeds an electrical output power of 7mw to a small loudspeaker.

10,236 DIRECT-COUPLED TRANSISTOR CIRCUIT by R. B. Brown (Philco); U.S. Pat. 2,967,951, Issued Jan. 10, 1961

Several direct-coupled transistor circuits, including a monostable multivibrator, a bistable multivibrator, an amplifier, and a gating or modulating circuit, are described. The circuits derive advantages from the fact that certain alloy junction and surface barrier transistors will provide signal gain when collector-to-base voltage is zero, and when collector voltage is of the appropriate polarity with respect to emitter voltage. This allows the use of common bias sources, direct coupling of stages, and the use of transistors of only one conductivity type.



## OSCILLATORS (Cont'd)

10,237 STABILIZED BLOCKING OSCILLATOR by F. J. Mueller (U.S.A.); U.S. Pat. 2,972,061, Issued Feb. 14, 1961

A transistor blocking oscillator circuit which will provide a constant pulse output independent of the saturation characteristics of the transistor is described. Pulse length regulation is provided by means of a constant voltage source which is used as a power supply for the collector of the transistor through the feedback transformer. The voltage supply, which contains a diode limiter, is of such design that when feedback current reaches a specified level, the source impedance increases sharply, limiting feedback power and extinguishing the oscillator pulse. The arrangement provides a pulse length which is also virtually independent of changes in ambient temperature.

10,238 DESIGNING TUNNEL DIODE OSCILLATORS by W. C. Case (Inst. Tech.); Electronics, Vol. 34, pp. 68-72, Feb. 1961

Frequency-stabilized sinusoidal and square-wave generators using tunnel diodes are described. Relaxation oscillators are analyzed by piecewise linear approximation. For frequency stabilization, a resonant circuit (excited by the tunnel diode oscillation) oscillates close to its resonant frequency and provides a synchronizing signal to the tunnel diode. Using a short-circuited coaxial cable in place of the series inductance in a relaxation oscillator provides square wave generation. The square wave period is approximately four times the period required for the electromagnetic wave to travel the length of the cable. Push-pull and cascade circuits are used to increase the power or voltage output. The amplitude changes with bias, providing a simple method of modulation.

## SWITCHING CIRCUITS

10,239 METHODS OF ANALYSIS OF CIRCUIT TRANSIENT PERFORMANCE by L. Hellerman and E. J. Skiko (IBM); IBM J. Res. and Dev., Vol. 5, pp. 33-43, Jan. 1961

Some numerical methods applicable in obtaining the distribution of performance parameters associated with the transient behavior of switching circuits are surveyed. The methods considered are: (1) Monte Carlo, in which sample circuits are simulated on the IBM 704 and their performance is computed and tabulated. (2) Parameter sensitivity methods, including propagation of error, in which the first and second moments of the output distribution are estimated from parameter sensitivities; and a method using the total differential of the performance parameter to estimate the deviation of circuit behavior from its component deviations. (3) A surface fitting method, in which a formula for delay time is developed in terms of circuit component values. Each method is used to determine the delay time of a simple system. Their merits and drawbacks are compared and discussed, and estimates of the IBM 704 machine time necessary for implementation on a ten-transistor switching circuit are given.

10,240 A 100-db MICROWAVE SEMICONDUCTOR SWITCH by D. W. Feldman and B. R. McAvoy (Westinghouse Res. Labs.); Rev. Sci. Instr., Vol. 32, pp. 74-76, Jan. 1961

A dual-diode microwave switch providing in excess of 100 db switched attenuation with low insertion loss is described.

Switching time of the device, limited by the diodes, is  $3 \times 10^{-7}$  sec. Application of the switch in a 9000 Mc superheterodyne magnetic resonance spectrometer as a mixer crystal protector and as a microwave signal blanker is described.

10,241 SYMMETRICAL TRANSISTORS AS AC OR DC SWITCHES AND THEIR APPLICATIONS IN MODULATOR AND DEMODULATOR CIRCUITS by J. F. O. Evans, D. A. Gill, and B. R. Moffitt (Smiths Aircraft Instr. Ltd.); J. Brit. IRE, Vol. 21, pp. 143-149, Feb. 1961

It is shown that a symmetrical circuit containing a symmetrical or near symmetrical transistor should exhibit lower voltage and current drift than the more conventional circuits. A circuit with asymmetry complementary to a near symmetrical transistor will perform almost as well as the symmetrical circuit and will have zero "contact potential". Test results demonstrate that an equivalent input circuit drift rate in the range  $\pm 1.5 \mu\text{V}/\text{deg C}$  from  $-40^\circ\text{C}$  to  $+100^\circ\text{C}$  can be expected for a very large percentage of any batch. The relationship between drift rate, circuit impedance and ambient temperature is examined. Various applications of these switches are discussed including modulators, demodulators and precision ac switches.

10,242 POWER TRANSISTOR CONTROL CIRCUIT by J. Baude (Allis-Chalmers); U.S. Pat. 2,972,685, Issued Feb. 21, 1961

An improved transistor switch which is suitable for use with AC circuits is described. The switch comprises two PNP type transistors connected in an opposing parallel manner so that the current passes through a transistor which is polarized for favorable conduction during both half cycles of alternating current. In this manner, the efficiency and current carrying capacity of the switch are improved. A series of transistorized control stages is used to isolate the bases of the current carrying transistors from the control signal.

Avalanche Transistor Trigger Circuits - See 10,302

## SIGNAL CONVERTERS

10,243 ELIMINATION OF EVEN-ORDER MODULATION IN RECTIFIER MODULATORS by D. G. Tucker (U. Birmingham); J. Brit. IRE, Vol. 21, pp. 161-167, Feb. 1961

Previous analytical treatments of rectifier modulator circuits have usually assumed that the time-varying-resistance function of the rectifiers is a square wave. Differences in behavior when the function is not only not square, but also contains even-order harmonics of the carrier frequency, are discussed. Among other and more general results, it is shown how even-order modulation products can be eliminated altogether in the ring, series and shunt types of modulator provided that (a) the carrier waveform comprises only odd harmonics and (b) the external circuit impedance is a pure resistance  $R$  at all odd-order modulation-product frequencies, and can be related to the rectifier resistance/voltage characteristic,  $r(V_C)$ , so that  $R^2 = r(+V_C) \cdot r(-V_C)$ . This condition coincides with that for minimum conversion loss.

10,244 USING VOLTAGE-VARIABLE CAPACITORS IN MODULATOR DESIGN by A. C. Todd, R. P. Schuck and H. M. Sachs (Armour Research); Electronics, Vol. 34, pp. 56-59, Jan. 20, 1961

The use of voltage-variable capacitors in cascade phase modulators and in single-sideband amplitude modulators is described.

## SIGNAL CONVERTERS (Cont'd)

The phase modulator has acceptable linearity over a deviation angle of  $\pm 25^\circ$  per section. An experimental angle modulator gave a deviation of  $\pm 50^\circ$  with good linearity. A 26db suppression of unwanted sidebands was obtained from a single-sideband generator. Design equations and circuit diagrams are given for phase and frequency modulators and single-sideband amplitude modulators.

Direct-Coupled Transistor Modulating Circuit - See 10,236

Use of Symmetrical Transistors in Modulator and Demodulator Circuits - See 10,241

10,245 FREQUENCY AND PHASE DISCRIMINATOR by N. E. Hogue (Collins Radio); U.S. Pat. 2,969,468, Issued Jan. 24, 1961

A transistor circuit capable of detecting both phase and frequency modulated waves which uses essentially the same components for phase and frequency detecting is described. The circuit is designed for use in low impedance circuits and does not require the use of critically designed RF transformers. A prototype model had an  $f_0$  of 455kc, pull-in range of  $\pm 30$  kc, and hold-in range of  $\pm 125$ kc.

10,246 SIGNAL MIXER by H. Rosenberg, and R. L. Fussell (Burroughs); U.S. Pat. 2,971,099, Issued Feb. 7, 1961

A signal mixer circuit which provides compensation for d-c signal loss and thus provides an output signal which represents the highest applied input signal is described. Compensation is provided through the use of a pair of constant current sources comprising a base connected silicon transistor and a low impedance voltage divider. Matched silicon diodes connected in parallel perform the function of selecting the highest input signal which is transmitted to the output. Minimum "take over" signal for 5 per cent accuracy has been found experimentally to be as low as 100 millivolts.

10,247 A SOLID-STATE MICROWAVE SOURCE FROM REACTANCE DIODE HARMONIC GENERATORS by T. M. Hylin (Texas Instr.), and K. L. Kotzebue (Watkins-Johnson); IRE Trans., Vol. MTT-9, pp. 73-78, Jan. 1961

The generation of harmonics with reasonable efficiencies has been made possible by the application of high Q nonlinear reactance diodes. An approximate solution for the conversion loss of harmonic generators utilizing these devices has been obtained and design curves relating conversion loss with harmonic number, diode Q, and voltage-capacitance coefficient are presented. Harmonic generators have been operated with silicon and gallium-arsenide mesa diodes in the UHF region and conversion losses approaching the theoretical value have been obtained. Three harmonic generation stages in miniature modular packages have been cascaded to obtained 7-mw output at S band. These stages were driven by a transistorized crystal-controlled oscillator and power amplifier which supplied 200 mw at 140Mc from 1.3 w dc.

10,248 DESIGN AND OPERATION OF FOUR-FREQUENCY PARAMETRIC UP-CONVERTERS by J. A. Luksch, E. W. Matthews, and G. A. VerWys (RCA); IRE Trans., Vol. MTT-9, pp. 44-52, Jan. 1961

A theoretical analysis of a four-frequency parametric-diode up-converter is presented, retaining both sum and difference frequencies generated by mixing of pump and signal. Upper and

lower sideband up-converters are compared, and it is shown that the gain limitations of the former can be overcome by combination with the latter, without appreciable loss of stability. Three different parametric amplifier configurations utilizing this four-frequency mode of operation have been designed, fabricated, and tested. These designs utilize sum-frequency up-conversion from 400 to 9400Mc, and have exhibited noise figures below 1.5db, gain in excess of 12 db, and bandwidths greater than 8Mc.

Optimum Design of Wide-Band Parametric Up-Converters - See 10,229

10,249 EXPERIMENTAL TUNNEL-DIODE MIXER by J. C. Greene and E. W. Sard (Cutler-Hammer); Proc. IRE, Vol. 49, pp. 350-351 (L), Jan. 1961

Results of experimental investigation of the performance of a tunnel diode mixer are described. Over-all noise factors of 13.2 db and 11.8 db and transducer gains of 4.6 db and 1.0 db were observed at the operating points of maximum transducer gain and minimum over-all noise factor respectively. These results were in fair substantiation of results predicted by D. I. Breitner. ("Noise Figure of a Tunnel Diode Mixer", Proc. IRE, Vol. 48, pp. 854-858, May 1960)

10,250 A TUNNEL-DIODE AMPLIFYING CONVERTER by L. E. Dickens and C. R. Gneiting (Johns Hopkins U.); IRE Trans., Vol. MTT-9, pp. 99-101 (L), Jan. 1961

Measurements of the performance of a tunnel diode mixer are discussed. The mixer utilized germanium diodes and operated at 1200Mc with an IF frequency of 30Mc and the local oscillator set at 1170Mc. The best calculated value for the noise figure was about 4.7db with a bandwidth of 4Mc. The gain was calculated to be about 26db. An experimental noise figure of 4.5 db and a bandwidth of about 4.0Mc were attained. With further fine tuning a noise figure of approximately 3db and a bandwidth of 1-2Mc were obtained. This condition resulted in very high conversion gain but was not extremely stable. It is pointed out that the choice of a tunnel diode mixer or a tunnel diode amplifier followed by a standard mixer depends upon the particular application.

## WAVEFORM GENERATORS

Tunnel Diode Square Wave Generators - See 10,238

Television Signal Generator - See 10,254

Waveform Reshaper - See 10,275

## OTHER BASIC CIRCUITS

10,251 A TRANSISTORIZED NEGATIVE FEEDBACK HIGH-Q FILTER by J. M. Brown (Brooklyn Polytech Inst.); U.S. Gov. Res. Rep., Vol. 35, p. 167 (A), Feb. 10, 1961 PB 148 984

A filter with a center frequency of 100 kcps and a pass-band of 30 cps (corresponding to a Q of 3300) is described. It was decided that the most desirable filter would be a circuit utilizing a transistor current amplifier and a bridge-tee network (a band



## OTHER BASIC CIRCUITS (Cont'd)

op network) in a negative feedback arrangement. The analysis of the filter is based primarily on the use of appropriate transistor incremental models, signal flow graphs and root locus techniques.

Active Low-Pass Filter for Biological Potential Amplifiers - See 10,252

## APPLICATIONS OF SOLID STATE DEVICES

### SCIENTIFIC AND MEDICAL

High Current Potentiostat for Polarization Studies - See 10,289

Maser Radiometers for Radio Astronomy - See 10,257 and 10,258

10,252 AN ACTIVE LOW-PASS FILTER FOR BIOLOGICAL POTENTIAL AMPLIFIERS by G. White (White Instr. Labs.); IRE Trans., Vol. BME-8, pp. 2-4, Jan. 1961

An active RC filter with an m-derived low-pass response is described. Having a cutoff of 45 cps and a sharp attenuation peak at 60 cps, the filter is particularly suitable for eliminating power-frequency interference from EKG, EEG, or other biological potential amplifiers. It is small in size and requires only one 12AX7 or its transistor equivalent for the active elements. Typical design data and performance curves are given.

10,253 MEASURING THE HEART RATE OF AN ACTIVE ATHLETE by D. W. Hoare (Marconi's Wireless Tel.) and J. M. Wilson (Coll. of Technology); Electronic Engrg., Vol. 33, pp. 18-20, Jan. 1961

A system developed for measuring the heart beat rate of an athlete while he is in action is discussed. Two electrocardiac channels are fed into a gating circuit which provides discrimination against interference due to muscle noise. The gating circuit triggers a monostable multivibrator; this in turn frequency modulates a sub-carrier which amplitude modulates the crystal-controlled transmitter. The equipment is transistorized and the design is such that the system can be extended to transmit additional physiological information.

Transistorized Audiometer - See 10,315

### TELEVISION

10,254 ALTERNATING SIGNAL GENERATOR by J. Marley (Hazeltine); U.S. Pat. 2,969,470, Issued Jan. 24, 1961

A signal generating circuit designed to provide the energizing voltages needed for the transistorized portions of television circuits is described. The signal is derived from the line synchronizing pulse of the television receiver utilizing the carrier

storage phenomenon occurring in a junction transistor. The signal generator includes a resonant circuit, tuned to a frequency related to the scanning pulse frequency, which develops the stored carrier signal into the desired signal.

10,255 AUTOMATIC CONTRAST AND BRIGHTNESS CONTROL CIRCUITS FOR TELEVISION RECEIVERS by M. C. Gander and P. L. Mothersole (Mullard Res. Labs.); Mullard Tech. Commun., Vol. 5, pp. 227-230, Jan. 1961

The use of a photoconductive cadmium sulfide cell to control automatically the contrast and brightness of a television picture with changes in the ambient illumination is discussed. The cell can be used as a coupling device between the video amplifier and the cathode ray tube or it can be incorporated into the a.g.c. system of the receiver. Circuits for both methods of control in receivers designed for positive and negative modulation are described and the relative advantages are discussed.

Video Tape Recorder - See 10,313

### TELEPHONY

10,256 ELECTRICAL CIRCUITS FOR COMMUNICATION NETWORKS by R. E. Lunney (Bell Labs.); U. S. Pat. 2,972,683, Issued Feb. 21, 1961

A simplified switching control network for the establishment and control of communication paths in networks such as telephone central office networks is described. The circuit utilizes a transistor flip-flop which is normally maintained in the non-conducting state. When a proper signal is applied, the flip-flop switches on, providing a low impedance ground to the junctor or mactor circuit which in turn establishes a communication path through the network. A repetition of the initiating signal terminates the connection.

Light-Controlled Tone Generator for Monitoring Telephone PABX Switchboards - See 10,235

### MICROWAVES

X-Band Parametric Amplifier for Radar - See 10,224

10,257 AN OPERATIONAL RUBY MASER FOR OBSERVATIONS AT 21 CENTIMETERS WITH A 60-FOOT RADIO TELESCOPE by J. V. Jelley and B. F. C. Cooper (Harvard Coll. Observ.); Rev. Sci. Instr., Vol. 32, pp. 166-175, Jan. 1961

A maser preamplifier designed for radiometry at a wavelength of 21 cm is described. The maser is mounted at the focus of the 60-ft reflector of the Harvard College Observatory and is being used principally for observations of hydrogen-line radiation from extra-galactic nebulae. An automatic gain stabilization system for the maser using a modulated-noise reference signal is described and an example of an observation made with this stabilization scheme is included. The total input noise temperature of the radiometer is 85°K without the gain stabilization, and 148°K with the stabilization.

10,258 RECENT DEVELOPMENTS AND OBSERVATIONS WITH A RUBY MASER RADIOMETER by M. E. Bair, J. J. Cook, L. G. Cross, and C. B. Arnold (U. Michigan); IRE Trans.,

## MICROWAVES (Cont'd)

Vol. AP-9, pp. 43-49, Jan. 1961

An x-band ruby maser radiometer is discussed. In particular, recent developments in the equipment design are detailed. Observations of radio sources are discussed, and response curves with and without the maser preamplifier are given. The detection of 3.45 cm radiation from the planet Saturn is reported and the equivalent blackbody disk temperature is calculated. The future of the maser amplifier in radio astronomy is considered.

10,259 PULSED MILLIMETER-WAVE GENERATION USING FERRITES by B. J. Elliott, T. Schaug-Pettersen and H. J. Shaw (Stanford U.); IRE Trans., Vol. MTT-9, pp. 92-94, Jan. 1961

A method for generating pulsed RF energy in the millimeter-wave spectrum is described. Low-loss garnets are used in the uniform precessional mode to store energy at S band and radiate at a higher frequency, which is controlled by the total magnetic field. Details of a K-band generator which operates at frequencies up to 32 kMc are given.

Microwave Generator Using Varactor Diode Harmonic Generators - See 10,247

Dual-Diode Microwave Switch - See 10,240

10,260 PERIODIC SOLUTIONS OF THE WAVE EQUATION WITH A NONLINEAR INTERFACE CONDITION by W. L. Miranker (IBM); IBM J. Res. Dev., Vol. 5, pp. 2-24, Jan. 1961

The problem of the voltage oscillations in a transmission line when a crystal diode is placed in shunt in that line is discussed. In particular the response of this line to periodic driving voltages is considered and the periodic responses are studied. This physical situation is shown to lead to the mathematical model of the wave equation in the voltage in a domain with an internal boundary (the interface), at which the voltage is required to satisfy a nonlinear jump condition. By an application of Gauss' theorem, the problem is reduced to a nonlinear difference-differential equation. In the case that the generator driving the line is matched to it, this family of equations reduces to a family of nonlinear differential equations. The periodic solutions of these two classes of equations are studied.

10,261 A VARIABLE HYPER-FREQUENCY POWER DIVIDER [in French] by D. Milanovic (Faculté Electrotechnique, Belgrade); Onde Elect., Vol. 41, pp. 180-183, Feb. 1961

A practical form of a power divider for hyper-frequencies using directional coupling between two wave guides and the Faraday effect in ferrites is described. The directional coupling is simply a hybrid junction having 3 db coefficient of coupling.

## TAPE RECORDERS

10,262 THE MAGNETIC TAPE RECORDING PROCESS IN TERMS OF THE PREISACH REPRESENTATION by G. Schwantke (Heinrich Hertz Inst. Schwingungsforschung); J. Audio Engrg. Soc., Vol. 9, pp. 37-47, Jan. 1961

The magnetic tape recording process is studied by means of the statistics of Barkhausen jumps. The representation of the recording process by the Preisach diagram leads to a unified and easily handled theory for all cases and permits an explanation

of all interesting effects not previously understood. The method holds the possibility of a quantitative explanation of all properties through a more exact knowledge of the statistics of the specific material.

10,263 ON THE MODULATION NOISE OF A MAGNETIC TAPE RECORDING [in German] by P. A. Mann (Telefunken); Arch. Elekt. Uebertragung, Vol. 15, pp. 18-24, Jan. 1961

The active layer of magnetic tape is considered to consist of elementary magnetic domains with random positions and orientations. Each domain is supposed to be a single cubic crystal capable of carrying a magnetic moment in a direction parallel to one of its axes only. It is assumed that the remanent magnetic moment of each particle is proportional to the maximum magnetic field strength it had been exposed to during the recording process, and to the cosine of the smallest angle between the direction of the field and one of its axes. The voltage that, under these assumptions, appears across the terminals of the reproducing head, and its integral, representing the received signal plus noise, are calculated for a sinusoidal signal and a rectangular pulse. In particular the case of the sinusoidal signal is discussed with the aid of the correlation function. It is found that the average noise amplitude shows a time variation at the rate of the signal, the spectral distribution of the noise power does not depend on the signal frequency, and the noise power per unit frequency falls off exponentially with increasing frequency.

Video Tape Recorder - See 10,313

## COMPUTERS

10,264 TRANSISTOR LIFE IN THE TX-O COMPUTER AFTER 10,000 HOURS OF OPERATION by D. J. Eckl and R. L. Burke (Lincoln Lab.); U.S. Gov. Res. Rep., Vol. 35, p. 50 (A), Jan. 13, 1961 PB 150 601

The results of a test of 58 microalloy transistors and 800 surface barrier transistors after 10,000 hours of operation in a computer are presented. During the entire period of operation, only one transistor - a light-pen-amplifier - was removed as an "uncaused" failure. No data are available on "personnel-induced" failures. Approximately 10 per cent of the transistors tested fell below original acceptance specifications, but they were returned to service and have operated normally. Certain of the parameter variations were unexpected and appear to be characteristic of surface changes in the surface-barrier transistor. The results of the transistor tests so far are excellent and surpass those originally anticipated.

10,265 MARGIN CONSIDERATIONS FOR AN ESAKI DIODE-RESISTOR OR GATE by H. K. Gummel and F. M. Smits (Bell Labs.); Bell Sys. Tech. J., Vol. 40, pp. 213-232, Jan. 1961

An Esaki diode-resistor logic, powered from a three-phase supply and involving OR gates, is analyzed. Practical switching times are of the order of  $10 \sqrt{RT/C}$ . The voltages at which the current maximum and the current minimum occur set an upper limit on the achievable logical gain. For a sum of fan-in plus fan-out of 3, the margins on key diode and circuit parameters must be better than  $\pm 2$  per cent, with all margins assumed equal. The margins can be  $\pm 3.5$  per cent for a fan-in plus fan-out of 2, which, however, restricts the applications to shift registers, flip-flops, and the like.



266 A SURVEY OF TUNNEL-DIODE DIGITAL TECHNIQUES by R. C. Sims, E. R. Beck, Jr., and V. C. Kamm (Bendix); Proc. IRE., Vol. 49, pp. 136-146, Jan. 1961

Techniques for using tunnel diodes in high-speed random-access memories and in dynamic logic systems utilizing multiphase clock sources are discussed.

267 CALCULATED WAVEFORMS FOR TUNNEL DIODE LOCKED PAIR by H. R. Kaupp and D. R. Crosby (RCA); Proc. IRE., Vol. 49, pp. 146-154, Jan. 1961

An introductory analysis of the tunnel diode locked-pair circuit is presented. The characteristics of the tunnel diode, together with the simplicity of the locked-pair circuit, make it a major contender for use as a high speed computer element. High speed and high gain are the main advantages of the locked-pairs; the three phase power supply and lack of a simple means for logical inversion are its main disadvantages. The basic circuit consists of two tunnel diodes in series, the node common to the tunnel diodes being both the input and output terminal. As a computer element, the locked-pair functions in much the same manner as the phase-locking harmonic oscillator (PLO). Like the PLO, the locked-pair overcomes the difficulty of coincident input and output terminals by using a three-phase voltage source. The feasibility of using a digital computer to solve nonlinear circuit problems is also demonstrated. A digital computer makes possible an exact solution by doing away with relatively ineffectual linear approximation techniques. Furthermore, the stray parameters associated with laboratory work at high frequencies are excluded, thereby disclosing the true nature of the circuit.

Miniature Magnetic Logic Element - See 10,314

268 THE CORE AMPLIFIER, A BASIC CIRCUIT FOR ELECTRONIC SWITCHING EQUIPMENT by H. Kok (N. V. Philips); Philips Telecommun. Rev., Vol. 22, pp. 81-93, Jan. 1961

The principle and design of the core amplifier, a storage and switching element consisting of a transistor and a ferrite core assembly, are discussed. Applications of the core amplifier in logical circuits such as counting circuits, code converters and circuits for matrix control are described. A method for the supervision of logical circuits made up of core amplifiers is also given.

269 DEVELOPMENT OF A MAJORITY GATE FOR IMPROVING DIGITAL SYSTEM RELIABILITY by R. Wasserman (Hermes Electronics); U.S. Gov. Res. Rep., Vol. 35, p. 81 (A), Jan. 1961 PB 150 484

A logical design procedure for the efficient use of redundancy in improving the reliability of digital systems is discussed. This calls for the development of a highly reliable, simple constructed, majority gate. Requirements and design considerations for the majority gate using magnetic cores as logical building blocks are presented. Logical design principles for a shift register, dynamic flip-flop, logical gate functions, binary counter, comparator, and two input full adder are also considered. A 6-core majority gate module and a 9-core majority gate module are discussed.

270 INERTIAL SELECTION FOR MAGNETIC CORE LOGIC by R. H. Tancress (Lincoln Lab.); U.S. Gov. Res. Rep., Vol. 35, p. 190 (A), Feb. 10, 1961 PB 152 637

The Inertial Selection scheme in which logical functions can be performed by connecting toroidal ferrite cores together with single turn windings only is described. A "flux gain" feature is thereby obtained which allows more flux to be switched into a receiving core than is received there from a transmitting core. To achieve these characteristics, the Inertial Selection scheme utilizes two thresholds of low coercive force ferrite cores. It also uses the property that one of these thresholds can be changed by electrical means. The factors involved in understanding these magnetic characteristics and their utilization in logic applications are discussed in detail.

10,271 COMPUTER-DEVICE APPLICATIONS OF THIN FERROMAGNETIC FILMS (Sperry Rand); U.S. Gov. Res. Rep., Vol. 35, pp. 82-83 (A), Jan. 13, 1961 PB 150 767

The results of a study of the application of thin ferromagnetic films to computers are reported. Anisotropic, "double threshold," and "rotating anisotropy" films have been considered for use as logic and memory devices. A plausible explanation of the unique properties of double threshold and rotating anisotropy films is given in terms of domain walls and impurity atom diffusion. Two NDRO memory devices using double threshold and rotating anisotropy films are described. An "and" gate, an "exclusive or" gate, and three types of full adder using thin films are described. An "and" gate, an "exclusive or" gate, and a NDRO memory element using double threshold films have been constructed and evaluated.

10,272 CRYOTRON LOGIC CIRCUIT by R. K. Richards; U.S. Pat. 2,969,469, Issued Jan. 24, 1961

A universal type of cryotron circuit which can be adapted to a wide variety of logical functions in a uniform manner and which allows the number of cryotrons required for the performance of a function to be held to a minimum is described. The simplifications are accomplished by performing the logical functions by means of appropriate connections to the output cryotrons from which the signals are derived rather than at the input cryotrons of the flip-flops to which the signals are sent, and by utilization of the push-pull technique for setting the destination flip-flops. Utilization of the circuit in AND, OR, addition, and other logic circuits is demonstrated.

Counting Chain for Remote Control Systems - See 10,295

10,273 ELECTRONIC COUNTING CHAINS by S. L. Hurst, E. I. White, and W. E. New, (Westinghouse Brake and Signal, London); U.S. Pat. 2,971,101, Issued Feb. 7, 1961

A transistorized, cascaded counting chain comprising a series of bistable circuit stages connected with transistors whose function it is to provide variable control of interstage coupling is described. The variable interstage impedance serves as a means to assure that stepping pulses are applied to succeeding stages in the proper sequence. The circuit may be utilized to provide a predetermined pattern of output pulses from a train of random input pulses or, if driven continuously, may serve as a frequency divider or ring counter.

10,274 TRANSISTOR BINARY COUNTER by O. P. Clark (Bell); U.S. Pat. 2,972,062, Issued Feb. 14, 1961

A transistor binary counter which is sensitive to trigger pulses of very low amplitude and high repetition rate and which operates with a low power clock pulse is described. The counter comprises a pair of junction transistors cross-connected to form a bistable multivibrator. The trigger source is connected to the

collectors of the transistors through a pair of "steering" diodes, each of which is biased by the collector of the opposite transistor. A pulse delay maintains each diode bias substantially unchanged during the interval of the triggering pulse; thus all of the energy of the pulse is utilized to produce correct operation of the counter.

10,275 A MULTI-PURPOSE COMPUTER ELEMENT by C. B. Taylor (E.M.I. Electronics Ltd.); Electronic Engrg., Vol. 33, pp. 98-99, Feb. 1961

A long-tailed pair waveform reshaper which, together with a number of logical gates, has many uses as a basic element for a computing system is described. The main design aim was to produce an economical binary counter stage employing transistor-diode logic, but among the other possible uses of the element are a pulse generator, simple reshaper, delay with reshaped bi-phase outputs bistable element, and free running square wave generator.

10,276 SATURABLE CORE MAGNETIC AMPLIFIER FOR NEON INDICATOR LAMPS ON TRANSISTOR SCALERS by H. Mima and K. Tonguh (Kobe Kogyo); Rev. Sci. Instr., Vol. 32, p. 220, Feb. 1961

A transistor binary scaling circuit which utilizes a magnetic amplifier saturable with low d-c collector or emitter current as a switch for a neon lamp indicator is described. Features of the magnetic amplifier switching method are: (1) small size, ruggedness and permanent life; (2) very low cost; (3) simple circuitry; (4) "AND" circuits and "OR" circuits can be constructed easily; (5) versatile circuit design is possible.

10,277 AN INTEGRATED BINARY ADDER by M. E. Szekely, S. M. Marcus, and J. T. Wallmark (D. Sarnoff Res. Ctr.); U.S. Gov. Res. Rep., Vol. 35, p. 81 (A), Jan. 13, 1961  
PB 152 045

An integrated binary full adder which uses unipolar field-effect transistors as its active and passive elements is described. A binary full adder is a computer circuit that adds three binary numbers, X, Y and a carry from a previous stage, C, giving two outputs, one for the sum and one for the carry to the next stage. Each one of these binary numbers may be 0 or 1 corresponding to eight possible combinations. The design is developed in terms of conventional circuitry, and then extended to an integrated module. The active element used throughout the adder is the unipolar field-effect transistor (UT) the operation of which is described. The only passive elements used are resistors which are also in the form of unipolar transistors. The logic concept used is direct-couple unipolar transistor logic (DCUTL) which is also described.

10,278 ELEMENTS AND UNITS OF FERRITE-TRANSISTOR CELL ONE-CYCLE PARALLEL ARITHMETIC DEVICE OF DIGITAL COMPUTER [in Russian] by M. I. Petrukhin; Avtomatika: Telemekhanika, Vol. 22, No. 2, pp. 199-208, 1961

The design of one-cycle delay circuits, a symmetric output trigger, a shift register and of a counter-type adder for a ferrite-transistor cell parallel arithmetic device are discussed.

Computer Simulation of a Cryotron Adder - See 10,210

10,279 PATTERNS IN THIN FILMS MAKE FAST NONDESTRUCTIVE MEMORIES by J. W. Hart (Burroughs); Electronics,

Vol. 34, pp. 126-129, Feb. 17, 1961

Formation of irreversible domains in thin magnetic films to make a nondestructive memory capable of operating at 10 Mc is described. A single domain is formed by application of orthogonal fields. An irreversible domain of opposite state is then formed inside this domain by the application and removal of a transverse field over a small area. The dipoles in the small area rotate toward  $90^\circ$ . The demagnetizing field of the neighboring domain generates an mmf causing the dipoles to rotate past  $90^\circ$ . When the transverse field is removed, the mmf due to the demagnetizing field rotates the dipoles to the opposite state. If a transverse field is again applied, the dipoles rotate toward  $90^\circ$  but return to their prior state upon removal of the field. A continuous readout of 1000 pulses a second for one day indicated no change in the sense signal. Identical sense signals were obtained from consecutive read pulses 100 nanoseconds apart.

10,280 CHARACTERISTICS OF THINLY COATED MAGNETIC MEMORIES [in French] by L. Gerardin (Cie Francaise Thomson Houston); Onde Elect., Vol. 41, pp. 66-80, Jan. 1961

The characteristics of memories utilizing thin ferromagnetic layers, particularly the physical processes which occur during the reversal of magnetization, are discussed. It is shown that reversal times of the order of 10 millimicroseconds are possible in such memories if advantage is taken of the magnetic characteristics associated with thin layers.

10,281 EXPERIMENTS ON MAGNETIC TAPE READOUT WITH AN ELECTRON BEAM by M. M. Freundlich (Airborne Inst. Lab.), S. J. Begun and D. I. Breitzer (Clevite), J. B. Gehman (Thompson Ramo Wooldridge), J. K. Lewis (Dept. Defense); Proc. IRE, Vol. 49, pp. 498-509, Feb. 1961

A readout system in which a magnetic tape is bent over a cylinder and an electron beam is made to pass across the recorded track is described. The electrons close to the tape form a cycloid pattern which is deflected across the entrance slit of a Faraday collector, thereby producing an output signal corresponding to the recorded information. At present, some practical limitations prevent the full realization of the system's potential. The ultimate limitation is the shot noise of the electrons. Theoretical considerations indicate that if suitably recorded a 3-Mc-wide video signal, for example, could be reproduced with a signal-to-shot-noise ratio of 30 db and with an area packing density of 0.85 cycle per square mil.

10,282 A MAGNETIC ASSOCIATIVE MEMORY by W. L. McDermid and H. E. Petersen (IBM); IBM J. Res. Dev., Vol. 5, pp. 59-63, Jan. 1961

The construction of an experimental magnetic core associative memory that is also capable of being interrogated conventionally is described. The method of nondestructive readout and the construction of suitable detectors to read the available signal energy are discussed. Memory capacities of several hundred words appear feasible with a single interrogation driver. A search and retrieval time of 6 nsec on a 36-bit search basis has been achieved.

10,283 ANALYSIS OF FERRITE CORE SWITCHING FOR PRACTICAL APPLICATIONS by P. A. Neeteson (Philips); Electronic Applications, Vol. 20, pp. 133-152, 1959-1960

Analysis of the behavior of magnetic switching materials having rectangular hysteresis loop properties, based as closely as possible on the physical background of the flux reversal process



necessarily leads to expressions which are too complex to handle in the practical design of circuits in which the core properties are used. On the other hand, a rough approximation may under possible design procedures leading to quick results, but experimental corrections may be required at a later stage. A solution of this problem in which the derived analytical expressions are in close agreement with the physical behavior of the material and are at the same time fairly easy to apply to circuit design is presented. Resistive and inductive loading of the cores are discussed, and also cores driving a line of cores in a memory stack, current sources being used to drive the cores. The operation of voltage-driven cores is also dealt with.

10,284 MAGNETIC FILM MEMORY DESIGN by J. I. Raffel, S. Crowther, A. H. Anderson, and T. O. Herndon (Lincoln Lab.); *Proc. IRE*, Vol. 49, pp. 155-164, Jan. 1961

The use of thin magnetic films of permalloy for high-speed digital storage is discussed. A simple rotational model modified to include the effects of wall switching and dispersion of the preferred direction of magnetization provides a basis for describing properties of engineering interest. A selection system has been chosen which allows great latitude in film uniformity. Production of films with magnetic properties uniform to within  $\pm 10$  percent is readily achieved. Specifications for operation in a destructive mode can easily be met by existing film arrays; the nondestructive mode is considerably more stringent unless very small signals can be tolerated. The first film memory, which has been in reliable operation since the summer of 1959, has stored ten-bit words and has been operated with a minimum cycle time of 0.4  $\mu$ sec. Higher speed and larger capacities will require higher bit densities and improved techniques to minimize undesirable coupling between drive and sense lines. The use of  $10 \times 60$  mil rectangles, balanced sense windings, and longer words will hopefully permit memories of about 200,000 bits with cycle time under 0.2  $\mu$ sec.

10,285 ELECTRONIC SHIFT REGISTER by H. A. Druker and R. Brown (Briggs Associates); U.S. Pat. 2,967,250, Issued Jan. 3, 1961

A transistorized one stage per bit shift register circuit which is critically responsive to data pulse lengths or shift pulse periods is described. The circuit uses one flip-flop per stored bit. A delay pulse former network is connected between the output of one flip-flop and the input of the next one. This delayed pulse, which can not vary with shift pulse duration differences, serves as a data input pulse to the next flip-flop. The flip-flops can drive loads from either side so that static direct current levels are available for the data or its complement. Output signals are not restricted to exact clock pulse periods or to transition operation of the flip-flops, permitting readings to be taken from all stages in parallel, or permitting serial output information to be sampled at any time between two successive shift pulses.

10,286 TRANSISTORIZED ELECTRONIC ANALOG MULTIPLIER by S. Deb and J. K. Sen (Calcutta U.); *Rev. Sci. Instr.*, Vol. 32, pp. 189-192, Feb. 1961

The exponential current-voltage characteristic of the input of a grounded base junction transistor is utilized to construct an analog multiplier. Four-quadrant operation is obtained by using two channels — one with pnp and the other with npn transistors. Design considerations of the various components of the multiplier are discussed. It is shown that the performance of

the multiplier — particularly in respect of bandwidth — compares favorably with that of the other types described in the literature.

10,287 DIODE LATTICE MULTIPLIER WITH INHERENT LIMITING by G. L. Hobrough (Hunting Survey); U.S. Pat. 2,967,954, Issued Jan. 10, 1961

A lattice multiplier employing matched silicon diodes is described. The multiplier processes two input signals containing a frequency component in such a manner that the resulting output signal is effectively a measure of the portion of time during which the two signals have the same polarity. The multiplier is highly stable and extracts essentially only signal information at or near the zero crossings of input wave forms.

## POWER

10,288 SEMICONDUCTOR CAPACITOR-INPUT FILTER POWER SUPPLIES by L. P. Hunter (IBM); *Solid State J.*, Vol. 2, pp. 19-23, Feb. 1961

The analysis and design of semiconductor capacitor-input filter power supplies, both half wave and full wave, are discussed. Good results are obtained using simple curves and approximation formulae instead of using exact analysis which is very time-consuming even in simple circuits because of the non-linearity of the semiconductor rectifier characteristic.

10,289 HIGH CURRENT ELECTRONIC POTENTIOSTAT by D. N. Staicopoulos (du Pont); *Rev. Sci. Instr.*, Vol. 32, pp. 176-178, Jan. 1961

The design of a high current transistorized potentiostat capable of delivering currents of the order of 5 amp for anodic or cathodic polarization studies at controlled potentials is presented. The range of potentials possible is determined only by the characteristics of the test electrode/solution interface. The response of this instrument is such that switching from maximum cathodic to maximum anodic potentials and vice versa can be accomplished within  $10^{-3}$  sec. Analysis indicates that it is possible to effect a tenfold increase in the current-carrying capacity of this potentiostat with only minor modifications. The combination of high speed, short risetime, and high current instantly available for either anodic or cathodic polarization is unique in this potentiostat and provides outstanding versatility.

10,290 A DC POWER SUPPLY USING TRANSISTORS AND ZENER DIODE REFERENCE SOURCES by R. E. Aitchison and C. T. Murray (U. Sydney); *Proc. IRE, Australia*, Vol. 22, pp. 26-27, Jan. 1961

A transistorized d-c power supply which utilizes a cascaded Zener diode reference system to achieve extremely low ripple and high mains stability is described. The unit can provide a constant voltage output variable from slightly below zero to about 12 v. with a maximum output current of 250 ma; a constant current variable from approximately one  $\mu$ a to 10 ma; and a constant voltage reference of 6 v, 0-1 ma. These ratings are useful in measurements and experimental investigations of transistor circuits and transistor characteristics.

## CONTROL

10,291 SPEED CONTROL OF DC MOTORS by M. J. Miller and G. V. Buckley (BBC); Electronic Tech., Vol. 38, pp. 63-67, Feb. 1961

Two systems for controlling the speed of small d-c motors employing transistorized equipment are described. The first is a phase-lock feedback system which combines an a-c signal proportional in frequency to motor speed with a standard reference frequency. An error signal and phase differential is derived and combined with a d-c signal which is proportional to motor speed. The combined signal constitutes the motor control voltage. The second system uses a simple velocity feedback principle. Stabilities of 0.1 per cent and better have been achieved with the first system at frequencies of 1-3 kc, and stabilities of up to 0.2 per cent with the second system.

10,292 ELECTRICAL CONTROLLER by W. H. Elliot and G. L. Yager (Cutler-Hammer); U.S. Pat. 2,972,684, Issued Feb. 21, 1961

A thermally controlled oil well pump control mechanism designed to discontinue pump operation when oil level declines below a desirable pumping level is described. The circuit uses a thermistor bridge and a transistor amplifier in conjunction with a timing device to control the starting and stopping of the pump motor. The appearance of gas in the oil flow stream reduces the heat dissipation of the immersed thermistor to a degree sufficient to change the bridge balance and in turn to activate relays which control the pump.

10,293 USING THERMISTORS AS SERVO ELEMENTS by I. C. Hutcheon (George Kent, Ltd.); Electronics, Vol. 34, pp. 52-55, Feb. 3, 1961

The substitution of indirectly heated thermistors for mechanical servo units is described. The basic circuit is a thermistor potentiometer. Two thermistors in series have their heaters differentially driven by a phase-sensitive demodulator with both heated equally under no-signal conditions. Application of an a-c signal increases one resistance and decreases the other, so that the common point moves toward one or the other end of the total resistance, according to the signal phase. Thermal inertia prevents significant modulation at frequencies above a few tens of cycles per second, and the device is directly analogous to a servo motor and potentiometer combination. Circuit applications of the device are presented.

10,294 USING VARISTORS TO SUPPRESS RELAY SPARKING by R. de Proost (M.B.L.E.) and R. Servranckx (Belgian Royal Mil. College); Electronics, Vol. 34, pp. 68-72, Jan. 20, 1961

The use of varistors to suppress sparking at relay contacts when switching inductive loads is described. The behavior of the varistor is attributed to the complex network of resistances in series and parallel formed by the contacts between the multiple crystals of the material and to the breakdown of the potential barriers arising at these points of contact. Nomographs and charts are given for selecting the proper varistor and typical examples are worked out. Experimental results indicate agreement with calculated values.

10,295 REGISTRY CIRCUITS FOR REMOTE CONTROL SYSTEMS by S. L. Hurst, and J. J. Ring (Westinghouse Brake and Signal); U. S. Pat. 2,971,100, Issued Feb. 7, 1961

A function registry circuit for electronic remote control systems of the continuously scanning type which accomplishes registry

with only a single bistable circuit for each stage of the counting chain and which incorporates sufficient delay to overcome pulse transmission delay times is described. The counting chain comprises a series of transistorized Eccles-Jordan circuits, only one of which is conditioned during each counting step in order to assure proper registration of all functions assigned to the entire system. The single chain construction provides economies of construction, use, and installation.

## INSTRUMENTATION

10,296 MEASUREMENT OF HALL VOLTAGES AT MICRO-WAVE FREQUENCIES by A. D. Rugari (Rome Air Dev. Ctr.); U.S. Gov. Res. Rep., Vol. 35, p. 209 (A), Feb. 10, 1961  
PB 152 405

The measurement of Hall voltages in indium arsenide and indium arsenide phosphide crystals at frequencies of 3500 and 9050 Mc and its application to the measurement of microwave power is described. The results obtained show approximately two orders of magnitude of improvement over other work reported in this area and indicate the feasibility of an automatic field power measuring instrument using the Hall effect.

10,297 A RECORDING SYSTEM FOR GALVANOMETER BEAM DEFLEXIONS by G. E. Alexander and G. G. Eichholz (Dept. Mines and Tech. Surveys); Electronic Engrg., Vol. 33, pp. 38-39, Jan. 1961

Equipment designed to observe and record the passage of a focused light beam at a series of points on a galvanometer scale to an accuracy of 1 mm is described. The light-sensitive detector used is a silicon solar cell and the equipment uses transistors throughout.

10,298 SENSITIVE OUTPUT INDICATOR FOR DIFFERENTIAL TRANSFORMER DISPLACEMENT DETERMINATIONS by D. Wobschall (U. Buffalo); Rev. Sci. Instr., Vol. 32, pp. 71-73, Jan. 1961

A transistorized circuit particularly designed as an output indicator for linear variable differential transformers is given. It is relatively simple to construct, adjust, and operate. The advantages of a phase-sensitive detector for the measurements of small displacements is discussed. Resolution of the unit is about 0.05  $\mu$ ; the linearity is about 1/4 per cent.

10,299 MAGNETIC-FIELD PICKUP FOR LOW-FREQUENCY RADIO-INTERFERENCE MEASURING SETS by M. Epstein and R. B. Schulz (Armour Res. Found.); IRE Trans., Vol. ED-8, p. 70, Jan. 1961

A magnetic-field pickup which utilizes the Hall effect in intermetallic semiconductors is described. Unlike a loop pickup, the sensor responds to magnetic flux density and thus is independent of frequency. Due to its extremely small size, it makes possible the measurement of magnetic fields in constricted regions. When used in conjunction with ferrite flux collectors, its sensitivity is  $10^{-7}$  gauss in the range of 30 cps to 15 kc. Details of design and construction are given.

Microwave Switch for a Magnetic Resonance Spectrometer -  
See 10,240



## INSTRUMENTATION (Cont'd)

10,300 MECHANICAL MEASUREMENT by M. Nalecz (Polish Acad. of Science, Warsaw); Electronic Tech., Vol. 38, pp. 5-17, Jan. 1961

A method of utilizing the Hall effect for the purpose of measuring non-electrical quantities is described. The transformation of mechanical displacement into electrical quantities is accomplished by moving a piece of Hall-effect material in a linearly non-uniform magnetic field. The resulting Hall voltage output will vary with the displacement to be measured. The non-uniform field is produced in the air gap of an electromagnet with specially shaped pole pieces, or between similar poles of two permanent magnets. Experiments conducted with ferrite magnets and a Siemens semiconductor plate yielded sensitivity to micron displacements with no electronic amplification.

Piezoelectric Probe for Plasma Research - See 10,213

10,301 THERMISTOR MICROMETHOD FOR MOLECULAR WEIGHT DETERMINATION by A. Wilson, L. Bini, and R. Hofstadter (American Cyanamid); Analyt. Chem., Vol. 33, pp. 135-137, Jan. 1961

A highly sensitive thermistor method for molecular weight determination is described. The method has been used with water, benzene, 1,4-dioxane, carbon tetrachloride, ethyl acetate, and chloroform as solvents. The apparatus is essentially a twin thermistor bridge, by means of which may be detected a temperature difference as low as  $1.5 \times 10^{-4}^{\circ}\text{C}$  arising from the difference in solvent activity between drops hanging on the thermistors at  $30^{\circ}\text{C}$ . A useful technique measures the unknown solution against a series of standards and thereby avoids a separate calibration.

10,302 FAST COINCIDENCE CIRCUITS UTILIZING AVALANCHE TRANSISTORS [in French] by J. C. Artiges and J. C. Guion (Service d'Electronique Phys., Orsay); J. Phys. Radium, Vol. 22, Suppl. to No. 2, pp. 53A-58A, Feb. 1961

The use of ordinary transistors operating with delayed collector induction (avalanche) in fast trigger circuits (rise time  $10^{-9}$  sec) is discussed. Fast coincidence circuits utilizing avalanche transistors have been constructed. Measurements performed on these circuits are described.

10,303 A PORTABLE INTEGRATING SCINTILLATION COUNTER by J. C. Harvey (Plymouth and Devonport Tech. College); Electronic Engrg., Vol. 33, pp. 28-31, Jan. 1961

A scintillation counter designed for use where the levels of activity are too low for the ratemeter type of arrangement to give sufficient activity, as for instance on exposed rock mass samples of rock in the laboratory, is described. A high speed electromechanical counter preceded by a decade scaler is used. The complete equipment, including the photo-multiplier power supply, is transistorized and is fully portable.

10,304 LOW-LEVEL LINEAR MICROSECOND GATE by P. R. Magon (U. Michigan); Rev. Sci. Instr., Vol. 32, pp. 68-71, Jan. 1961

A linear transmission gate for use in scintillation counter coincidence experiments is described. The gate is suitable for negative pulses of microsecond duration and is linear over a range of 0.01 to 5 v. The circuit is relatively simple, uses no vacuum tubes, and is reliable over long periods of use. The use of low-level gates can increase the usable counting rate of a multi-channel coincidence system by an order of magnitude.

10,305 FAST TRANSISTORIZED PULSE HEIGHT ANALYZER by A. Alberigi-Quaranta and B. Righini (U. Bologna and Istituto Nazionale di Fisica Nucleare); Nuc. Instr. Methods, Vol. 10, pp. 25-30, Jan. 1961

A completely transistorized single channel pulse height analyzer with a dead time of 0.13  $\mu\text{sec}$  is described. The channel width is determined by the passive characteristic of a delay line and is a constant percentage of the discriminator setting. Circuit diagrams and calibration curves at various frequencies are given.

10,306 MASS DISTRIBUTION OF FISSION FRAGMENTS IN THE THERMAL NEUTRON FISSION OF  $\text{U}^{235}$  by G. J. Safford, I. Schröder, J. A. Moore, and E. Melkonian, (Brookhaven Natl. Lab. and Columbia U.); Bull. Am. Phys. Soc., Vol. 6, Ser. II, p. 8 (A), Feb. 1, 1961

An investigation of mass distribution using two solid state detectors facing each other at a distance of 1 cm and a deposit of  $\text{U}^{235}$  on a VYNS foil midway between them is described. ( $\text{U}^{235}$  deposited on the surface of a detector was found to diffuse slowly into the detector.) The quality of the detectors is indicated by the 15/1 ratio of counts in the light fragment peak to that in the valley. The mass distribution is derived from the energies of the fission fragments by the relation  $M_1/(M_1 + M_2) = E_2/(E_1 + E_2)$ . In one set of measurements, an electronic dividing circuit computed the ratio  $E_2/(E_1 + E_2)$ , yielding the mass distribution for the fragments in the total kinetic energy range  $\Delta(E_1 + E_2)$  of about 20 Mev centered at the peak of the distribution. The familiar double peaked curve with a peak-to-valley ratio of better than 500/1 was obtained. In another, the mass distributions were determined for a series of 4-Mev intervals of the total kinetic energy by observing the kinetic energy distribution of one fragment in coincidence with  $(E_1 + E_2)$  in the corresponding intervals. The peak-to-valley ratio increases rapidly with increasing total kinetic energy.

10,307 TRANSISTORIZED VACUUM TRIP UNIT by D. Jones (Natl. Inst. Res. Nucl. Sci.); J. Sci. Instr., Vol. 38, pp. 51-53, Feb. 1961

A trip unit which operates relays in the interlock and protection circuits of a high-vacuum pumping system is described. The unit, which employs a thermocouple gauge and a transistorized d-c amplifier, is simple to construct and set up and has proved stable and reliable in operation.

## NEW PRODUCTS

10,308 GERMANIUM BACKWARD DIODE (Philco Corp., Lansdale, Pa.)

The IN3353 germanium backward diode, packaged in a TO-18 assembly, is announced. The device is designed for high frequency, low level applications and may be employed to complement tunnel diodes in both digital and small signal applications. Further applications are found in d-c restorers and high frequency gates, detectors, mixers, and modulators.

10,309 PLASTIC CASTING MACHINE (The Leal Corp.,

## NEW PRODUCTS (Cont'd)

P.O. Box 53, Oaklyn 6, New Jersey)

The Mark II/25 machine which can cast plastics based on reactive resins such as epoxy, polyester, or polyurethane, and other plastics which set by the admixture of two or more components, is announced. The machine employs a "Turvort" automixing head and can dispense up to 25 cc of resin per shot at any required ratio from 1:1 to 1:25 with an error of less than 0.1 per cent and at pressures up to 5,000 psig; liquid viscosity ranges from 10 to 50,000 centipoises can be handled. The Mark II/25 may be used to pot or encapsulate electronic components in production facilities.

10,310 CIRCUIT-CAPS (General Instrument Corp., Semiconductor Division, 65 Gouverneur St., Newark 4, New Jersey)

Circuit-Caps or special product assemblies, designed to customer specifications on electrical, physical, and environmental requirements, are announced. The encapsulations and hermetically-sealed assemblies provide circuit-level rather than component level reliability. Standard Circuit-Caps available include full wave bridge rectifiers, silicon tube replacement rectifiers, modulator quads, and high voltage rectifier assemblies in a variety of package configurations.

10,311 THIN-FILM MICROCIRCUITS (CBS Electronics, Microelectronics Section, Lowell, Mass.)

Customer specified thin-film circuits utilizing vacuum and chemical depositions of conductors and dielectrics are announced. Reproducible and stable microcircuits are attained by employing high-adhesion conductors of aluminum, chrome-gold, or copper-gold, precision resistors of Nichrome and Karma films, and precision capacitors of thin-film silicon monoxide.

10,312 MINIATURE LOW NOISE PRE-AMPLIFIER (Infrared Industries, Inc., P.O. Box 42, Waltham, Mass.)

Model ISL606 solid-state pre-amplifier is announced. The standard unit is hermetically sealed in a volume of less than one cubic inch. The unit operates from  $-40$  to  $+100^{\circ}\text{C}$  with a noise range of 1.1 to 1.8 db; modifications permit reduction of noise by 0.5 db and decrease in size by one-half. Performance characteristics show a voltage gain of 20 db with  $-3$  db

points at 2.5 and 900 cps. The device is specifically designed for use with infrared photoconductors and low-level transducers.

10,313 CLOSED CIRCUIT VIDEO TAPE RECORDER (Tokyo Shibaura Electric Company, Tokyo, Japan)

A low cost, single-head, closed circuit, video tape recorder, suitable for operation in research, industrial, college, and sports facilities, is announced. The new recorder employs a single rotating head which records an entire picture of a television field on one long track of one inch video tape. Tape speed is 15 ips and the audio track is 2 mm wide on the upper edge of the tape. The video head has an estimated life of 300 hours and replacement can be made in about 30 seconds as only the head itself is changed rather than the entire head assembly.

10,314 SUBMINIATURE MAGNETIC LOGIC ELEMENTS (Di-An Controls Inc., 944 Dorchester Ave., Boston 25, Mass.)

"PICO-BIT" logic elements, packaged in a 0.88 cubic inch volume and designed to operate under space-environment conditions, are announced. The elements can perform any of the nine basic logical functions and maintain full performance and reliability margins from  $-55^{\circ}$  to  $+125^{\circ}\text{C}$ , at unlimited altitudes, 0–100% RH, under severe shock and vibration stresses, and at frequencies up to 250 kc. PICO-BITS was developed for space applications where small size, minimum mass and low power are mandatory.

10,315 FULL-RANGE AUDIOMETER (Otarion Listener Corp., Ossining, N.Y.)

Model 1100, a portable and fully transistorized pure tone and speech audiometer that meets all ASA specifications, is announced. Unit dimensions are  $8 \times 15 \times 15$  inches and weight is 19 lbs with all accessories. The unit provides tone tests in nine steps from 250 to 8000 cycles, and speech tests either live by microphone, or through a recording; signals are presented by earphone to either or both ears with a balance control for regulating intensities; a monitor earphone, with balance control, also is provided. Threshold level ranges from 10 to 100 db in steps of 1 db, and response varies from low, normal, or to high pitch; the test tone can be interrupted manually or by automatic pulses, and a masking signal of adjustable intensity is provided.

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